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Individuals' Decisions and Group Behavior in Financial Economics

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To my wife Lindsey

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Individuals' Decisions and Group Behavior in Financial Economics

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This dissertation contains three chapters in financial economics that theoretically and empirically examine how individuals' investment decisions explain aggregate behavior.

The first chapter examines how reputational herding between fund managers depends on the fee structure, fund manager evaluation metric, market efficiency, and density of talented fund managers. Results show there are more equilibria involving herding between fund managers when net fund balance growth depends on reputation of talent rather than fund return. These inefficient equilibria are removed when the ratio of the performance fee rate to management fee rate is larger than calculated thresholds that depend on market efficiency and the density of talented fund managers. In the absence of performance fees, lower predictability of investment returns and a higher density of talented fund managers increase the desire for fund managers to deviate from efficient equilibria. The model also shows having fund managers

compete against each other induces herding when net fund balance growth depends on fund returns, but removes herding equilibria when net fund balance growth depends on reputation of talent.

The second chapter determines what herding networks exist between institutional investors and how herding depends on stock market volatility, degree of portfolio changes, and stock size. Using quarterly holding data from 2000-2010, I find stronger herding networks between similar types of institutions compared to institutions in the same metropolitan area. Furthermore, the herding network between similar types of institutions exists across metropolitan areas. Results show institutions herd more when making major portfolio changes than when making minor portfolio changes. The difference in herding between the two types of portfolio changes is greatest for small cap stocks which exhibit the highest levels of herding under both types of portfolio changes. The relationship between market volatility and herding by institutions is also examined and found not to have a strong correlation using quarterly holdings data.

The third chapter answers the question, "Can reasonable wind energy plant cost reductions or efficiency improvements precipitate immediate investment in wind energy in the absence of renewable energy Production Tax Credits?" I analyze a single entity considering an irreversible investment under uncertainty in wind power energy. The investor's decision to invest is dependent on investment cost, energy production efficiency, government policy, current price of electricity, and beliefs on future electricity prices. The results show that even with substantial cost reductions and efficiency improvements, Production Tax Credits are still needed to encourage immediate investment.

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Chapter 1

Performance-Based Fee Structures: A Possible Market Stabilizer and Herding Deterrence

1.1 Introduction

After a financial crisis, people determine where to place blame. Hedge funds have become a target for criticism because some argue their performance fees cause fund managers to take excessive risks (see Zuckerman (2008)). In contrast, others believe that hedge funds' investment structure creates a more stable financial market and should be encouraged by legislation (see Mallaby (2010)). This chapter analyzes the impact of performance fees on reputational herding and how herding depends on the fund manager evaluation metric, market efficiency, and density of talented fund managers.

Performance fees are fees fund managers charge investors that are based on a fund's return. Currently, less than 15 percent of all funds use performance fees (see Jaffe (2010)), but there is a growing trend towards performance-based fee structures. Hedge fund assets under management grew from $110 billion at the end of 1998 to roughly $2 trillion dollars in 2008 (see Eichengreen and Mathieson (1999); Zuckerman (2008))[1]. The growth in performance fees is not

[1] Mutual funds managed about $12 trillion in 2008 (see Zuckerman (2008)).

solely attributed to an increase in hedge funds. Putnam Investments recently introduced performance fees on several of its mutual funds, and other fund companies are planning on implementing performance fees on some of their funds (see Tarquinio (2010)). In the UK, there was a 138 percent rise in open-ended funds with performance fees between 2008 and 2010 (see Currie (2010)). In addition, Fidelity, Blackrock, Axa Investment Managers, Shroders, and JPMorgan Asset management all expect the usage of performance fees will continue to grow in the future (see Lawlor (2010)). To help prevent future crises, it is important to better understand performance-based fee structures and determine if policy makers should encourage or discourage their growth.

There are a number of theoretical papers that examine performance fees. Grinblatt and Titman (1989) use option pricing theory to value a performance fee as a call option held by the fund manager. Under a contract with asymmetric fees, a fund manager has the incentive to take large risks because she can earn large gains on the upside and lose little on the downside. Starks (1987) compares symmetric and asymmetric performance fees, concluding that symmetric fees mitigate adverse risk incentives.

Lynch and Musto (1997) also consider incentives induced by performance fees, but focus on unobservable fund manager effort. Their results suggest performance fees are better than management fees at extracting effort. They assume hedge fund managers are more skilled on average than mutual fund managers; therefore, performance fees are more common with hedge funds because the benefits of extracting more effort are greater for hedge funds. Grinold and Rudd (1987) acknowledge negative aspects of performance fees, but conclude that performance fees closer align a fund manager's reward to his skill. Furthermore, they find that poor and average managers are likely to fail faster with performance fees than they would under a traditional fee structure with only management fees.

Empirically, fee structures are difficult to examine because it is hard to obtain fee structure variation *ceteris paribus*. Due to an exogenously mandated law by the SEC in 1971[2], Golec and Starks (2004) were able to inspect how fund managers changed their portfolio risk levels after being required by law to remove asymmetric performance fees. Although the affected fund managers increased their risk levels after the law, Golec and Starks (2004) suggest the risk levels would have increased more without the law.

John Maynard Keynes summarizes the motivation for herding based on reputation considerations:

> *"Worldly wisdom teaches that it is better for reputation to fail conventionally than to succeed unconventionally."* Keynes (1936)

Fund manager herding has the potential to destabilize stock prices and form asset bubbles. Therefore, it is important to understand what mechanisms deter herding. Eichengreen and Mathieson (1999) argue that hedge funds often act

[2] *Investment Company Amendments Act of 1970*, amended Section 205 (effective December 14, 1971) required mutual funds to remove asymmetric performance fees (see Golec and Starks (2004)).

as contrarians and serve as "stabilizing speculators". If performance fees are a reason why hedge funds are contrarians, financial markets may become more stable if we encourage more fund managers to adopt a similar fee structure.

Herding is a popular topic in both economics and finance. Lakonishok et al. (1992) empirically examine herding between money managers and find minimal support for herding within individual stocks. Grinblatt et al. (1995) find higher levels of herding due to fund managers using positive-feedback strategies. Conversely, Sias (2004) shows strong correlation between fund managers' trades across reporting quarters that is not due to momentum strategies. In addition, Hong et al. (2005) find that fund managers located in the same city make similar investment trades. The existence of fund manager herding is further supported by Shiller and Pound (1989), who conducted a survey and find almost all institutional investors are influenced by peer communication when making investment decisions.

Bikhchandani et al. (1992) and Banerjee (1992) are two of the first theoretical papers that explain herding by modeling information cascades. Smith and Sorensen (2000) and Hendricks et al. (2012) are examples of theoretical herding papers in economics that evaluate how agents make costly decisions, but do not directly address herding in financial markets. In finance, Froot et al. (1992) present a model that shows investors with long horizons act efficiently, but investors with short horizons may herd on the same information that is sometimes completely unrelated to fundamentals. Although these papers address herding in a theoretical framework, Scharfstein and Stein (1990) is the only theoretical paper that directly models herding due to reputation concerns. Their model examines project managers contemplating a capital investment. "Smart" project managers are assumed to have correlated private signals pertaining to the profitability of the investment, and a manager's future wages are based on the updated belief that the manager is the "smart" type after her decision to invest or not has been made. Scharfstein and Stein (1990) find that project managers will rationally mimic the investment decision made before them and not use useful private information when future wages are based on reputation.

This chapter is the first to examine the effect of performance fees on reputational herding in a theoretical framework. In addition, this chapter examines how the desire to herd depends on the fund manager evaluation metric, market efficiency, and density of talented investors. I adapt the basic framework in Scharfstein and Stein (1990) to analyze eight cases under different fee structure and fund manager evaluation metric assumptions. Results show there are more equilibria involving herding between fund managers when net fund balance growth depends on reputation of talent rather than fund return. These inefficient equilibria are removed when the ratio of the performance fee rate to management fee rate is larger than calculated thresholds that depend on market efficiency and density of talented fund managers. In the absence of performance fees, lower predictability of investment returns and a higher density of talented fund managers increase the desire for fund managers to deviate from efficient equilibria. The model also shows having fund managers compete against each other induces herding when net fund balance growth depends on fund returns, but removes herding equilibria when net fund balance growth depends on reputation of talent.

The rest of the chapter is organized as follows. Section 1.2 describes the model and Section 1.3 shows equilibria found in eight cases under different fee structure and fund manager evaluation metric assumptions. Section 1.4 provides a discussion of the results from Section 1.3. Section 1.5 concludes the chapter. Appendix A.1 summarizes the eight cases under different fee structure and fund manager evaluation metric assumptions and Appendix A.2 contains a summary list of variables with descriptions. Details of calculations are in Appendix A.3.

1.2 The Model

1.2.1 Environment

The environment in this chapter is based on the model presented in Scharfstein and Stein (1990). Scharfstein and Stein (1990) consider the investment decisions of two project managers deciding whether to invest in a project, whereas this chapter considers the investment decisions of two fund managers deciding between two financial investments. This chapter extends the one period model in Scharfstein and Stein (1990) to two periods in order to create a trade-off between immediate profits and a good reputation for future profits. In addition, this chapter enriches the basic framework presented in Scharfstein and Stein (1990) by considering different fee structures and fund manager evaluation metrics.

There are two time periods. The first period exists between $t = 0$ and $t = 1$ and the second period exists between $t = 1$ and $t = 2$, where $t = 0, 1, 2$ denotes time. There are two possibilities for the state of the world each period. Consider state ω_G to be the "good" state and state ω_B to be the "bad" state. The state of the world is revealed at the end of each period: $\omega(t) = \omega_{G_t}$ or $\omega(t) = \omega_{B_t}$, for $t = 1, 2$. Argument t is used only for clarification purposes and is suppressed when appropriate to ease notation. Each period, the state of the world is independently drawn with equal unconditional probabilities:

$$\mathbb{P}(\omega_G) = \frac{1}{2}, \tag{1.2.1}$$

$$\mathbb{P}(\omega_B) = \frac{1}{2}. \tag{1.2.2}$$

There are two risk neutral fund managers that are indexed by $m = 1, 2$. Each fund manager must make a decision at the beginning of each period to invest using either a risky investment (Investment R) or a riskless investment (Investment RL). Denote the investment choice made by Fund Manager m at time t as $C^m(t)$, for $t = 0, 1$. $C^m(t) =$ Investment R_t^m when Fund Manager m chooses Investment R at time t and $C^m(t) =$ Investment RL_t^m when Fund Manager m chooses Investment RL at time t. Arguments m and t are used only for clarification purposes and are suppressed when appropriate to ease notation.

The two fund managers' investment decisions are made sequentially. The fund manager required to make the first investment is chosen at the beginning of each period with equal probability. Without loss of generality, let Fund Manager 1 be the fund manager chosen to invest first in the first period.

Denote $X^m(C, \omega, t)$, as the $t-1$ to t return Fund Manager m obtains by choosing investment C when the state of the world ω is realized for $t = 1, 2$. Investment RL earns the risk-free rate regardless of the state of the world:

$$X^m(\text{Investment } RL^m_{t-1}, \omega_{G_t}, t) = X^m(\text{Investment } RL^m_{t-1}, \omega_{B_t}, t) \quad (1.2.3)$$

$$= r. \quad (1.2.4)$$

The period investment return Fund Manager m earns when $C^m(t) = \text{Investment } R^m_t$ is a random variable that depends on the state of the world:

$$X^m(\text{Investment } R^m_{t-1}, \omega_{G_t}, t) = r_G, \quad (1.2.5)$$

$$X^m(\text{Investment } R^m_{t-1}, \omega_{B_t}, t) = r_B. \quad (1.2.6)$$

Arguments m and t are used only for clarification purposes and are suppressed when appropriate to ease notation.

State ω_G is associated with a greater period investment return than state ω_B for the risky investment:

$$r_G > r_B. \quad (1.2.7)$$

Riskier investments require larger unconditional expected returns. Therefore:

$$\mathbb{E}[\text{Investment } R] = \frac{1}{2} \cdot r_G + \frac{1}{2} \cdot r_B = r + \pi > r = \mathbb{E}[\text{Investment } RL], \quad (1.2.8)$$

where π is the risk premium associated with Investment R. A no-arbitrage condition is Investment R performs better than Investment RL in state ω_G, and Investment RL performs better that Investment R in state ω_B[3]:

$$r_G > r > r_B. \tag{1.2.9}$$

Each fund manager observes a private signal at the beginning of each period. Denote the private signal as $S^m(t)$ for $t = 0, 1$ and $m = 1, 2$. $S^m(t)$ can take on one of two values: $S^m_{G_t}$ or $S^m_{B_t}$. Arguments m and t are used only for clarification purposes and are suppressed when appropriate to ease notation. S_G represents information that suggests state ω_G is more likely than ω_B, and S_B represents information that suggests state ω_B is more likely to occur than ω_G.

In addition to observing a private signal, each fund manager is either innately "talented" with probability θ, or "untalented" with probability $1-\theta$. Denote Fund Manager m being talented as T_m and untalented as U_m. The ability of a fund manager is constant over all time periods. If a fund manager is talented, her private signal for a given period provides useful information about the state of the world for that period:

$$\mathbb{P}(S_G|\omega_G, T) \equiv p > \frac{1}{2}, \tag{1.2.10}$$

$$\mathbb{P}(S_G|\omega_B, \mathrm{T}) = 1 - p. \tag{1.2.11}$$

[3]The two fund managers are not allowed to short an investment, but the condition makes the investment decision for the two fund managers non-trivial.

If a fund manager is untalented, her private signal is uninformative:

$$\mathbb{P}(S_G|\omega_G, \mathrm{U}) = \mathbb{P}(S_G|\omega_B, \mathrm{U}) \equiv z. \tag{1.2.12}$$

Parameter p is a measure of market efficiency. A large value of p means that talented fund managers' private signals are informative of future price movements. Samuelson (1965) shows all price fluctuations are random in efficient markets, therefore large values of p are associated with inefficient markets.

A key characteristic of the environment is that a fund manager does not know her own type and neither do their investors nor the other fund manager. Therefore, the *ex ante* distribution of signals is the same for each type of fund manager so that a fund manager cannot infer anything about her own ability given just her own private signal:

$$z = \frac{1}{2}p + \frac{1}{2}(1-p), \tag{1.2.13}$$

$$z = \frac{1}{2}. \tag{1.2.14}$$

The left-hand side of (1.2.13) is the probability an untalented fund manager observes S_G and the right-hand side is the probability a talented fund manager observes S_G. With the given assumptions, both talented and untalented fund managers observe S_G with unconditional probability $\frac{1}{2}$ and observe S_B with unconditional probability $\frac{1}{2}$.

If one fund manager is talented and the other is untalented, their signals are drawn independently by the distributions given in (1.2.10), (1.2.11), and (1.2.12). If both fund managers are untalented, their signals are drawn independently by the distribution given in (1.2.12). In contrast, the independence assumption is not used when both fund managers are talented. If both fund managers are talented, their signals are perfectly correlated and they receive the same signal with certainty drawn from the distribution given in (1.2.10) and (1.2.11). The correlation assumptions are motivated by the idea that the information untalented fund managers use to make investment decisions can be considered noise, whereas talented fund managers commonly know what information is useful. The strong perfect correlation assumption between talented fund managers is used to simplify calculations.

1.2.2 Fund Manager Objectives

Each fund manager's objective is to maximize the expected present value of her cumulative two period profit. A fund manager's profit is produced by two types of fees:

1. Management Fees: A fixed percentage rate multiplied with the fund's net asset value,
2. Performance Fees: A fixed percentage rate multiplied with the fund's profit from the period before fees.

This chapter evaluates two types of fee structures:

1. The "traditional" fee structure consists of only a management fee,
2. The "performance-based" fee structure consists of both management and performance fees.

For simplicity, there are no high water marks or hurdle rates[4]. The performance fees are also symmetric[5].

Denote the management fee percentage rate for traditional fee structures as $MFRT$ and the management fee percentage rate for performance-based fee structures as $MFRP$. Because performance-based fee structures also include performance fees, assume $MFRT > MFRP$[6]. The performance fee percentage rate in performance-based fee structures is denoted as PFR.

Fund Manager m has a net fund balance of $NFB^m(t)$ at time t. Assume each manager is endowed at the beginning of the first period with:

$$NFB^m(0) = nfb \in \mathbb{R}_+, \quad \text{for } m = 1, 2. \tag{1.2.15}$$

The profit raised by management fees for Fund Manager m using a traditional fee structure is denoted as $MFT^m(t)$ for time period $t-1$ to t, for $t = 1, 2$. Similarly, the profit raised by management fees for Fund Manager m using a performance-based fee structure is denoted as $MFP^m(t)$ for time period $t-1$ to t, for $t = 1, 2$. The profit raised by performance fees for Fund Manager

[4] A high water mark means the manager receives performance fees only on increases in the net asset value of the fund in excess of the highest net asset value it has previously achieved. A hurdle rate means the fund manager does not charge a performance fee until the fund's annualized performance exceeds a benchmark rate.

[5] Most hedge fund performance fees are asymmetric, meaning that they only apply to positive excess returns. In contrast, mutual funds by law are required to have symmetric fees; the performance fees can either be a bonus or a penalty depending on the sign of the excess return (see Golec and Starks (2004)).

[6] In practice, it is usually the case that $MFRP > MFRT$ because hedge funds are currently a large portion of performance-based fee structures and hedge funds are usually more actively managed than mutual funds. This chapter compares two different fee structure types for a given fund. Therefore, it is reasonable that the fund manager would keep the same expected income and $MFRT > MFRP$.

m using a performance-based fee structure is denoted by $PF^m(t,X)$ for time period $t-1$ to t, for $t=1,2$. All arguments are used only for clarification purposes and suppressed when appropriate to ease notation.

$$MFT^m(t) = MFRT \cdot NFB^m(t-1), \tag{1.2.16}$$

$$MFP^m(t) = MFRP \cdot NFB^m(t-1), \tag{1.2.17}$$

$$PF^m(t,X) = PFR \cdot X^m(t) \cdot NFB^m(t-1). \tag{1.2.18}$$

The two fund managers and their investors are Bayesian updaters with regards to the posterior probability that Fund Manager m is the talented type, $m=1,2$. Denote $\hat{\theta}_m$ as the general notation for the posterior probability attached to Fund Manager m being the talented type by investors. $\hat{\theta}_m$ can take on values $\hat{\theta}_m^*$ and $\hat{\theta}_m^{**}$:

- $\hat{\theta}_m^*$ as the posterior probability attached to Fund Manager m being the talented type given $S^m(0)$ and $\omega(1)$,
- $\hat{\theta}_m^{**}$ as the posterior probability attached to Fund Manager m being the talented type given $S^1(0)$, $S^2(0)$, and $\omega(1)$.

The posterior probabilities calculated by the investors may differ from the fund managers' beliefs due to private signals not being revealed in the equilibria. Refer to $\hat{\theta}_i^m$ as the posterior probability that Fund Manager m calculates for Fund Manager i being the talented type.

Details on how the posterior probabilities are calculated are given in Appendix A.3.

This chapter examines four fund manager evaluation metrics distinguished by the net fund balance growth assumption between periods.

1. NFB^m growth depends only on $X^m(1)$:

$$NFB^m(1) = g\big(X^m(1)\big), \tag{1.2.19}$$

where $g : \mathbb{R} \to \mathbb{R}$ is a linear function increasing in $X^m(1)$, $m = 1, 2$. $g(\cdot)$ is positive over the domain defined by $X^m(1)$.

2. NFB^m growth depends on the relative value of $X^m(1)$ compared to $X^{-m}(1)$[7]:

$$NFB^m(1) = \tilde{g}\big(X^m(1) - X^{-m}(1)\big), \tag{1.2.20}$$

where $\tilde{g}(0) = nfb$, and $\tilde{g} : \mathbb{R} \to \mathbb{R}$ is linear function increasing in $X^m(1) - X^{-m}(1)$, $m = 1, 2$. $\tilde{g}(\cdot)$ is positive over the domain defined by $X^m(1) - X^{-m}(1)$.

3. NFB^m growth depends only on $\hat{\theta}_m$:

$$NFB^m(1) = f(\hat{\theta}_m), \tag{1.2.21}$$

where $f(\theta) = nfb$ and $f : (0, 1) \to \mathbb{R}$ is a linear function increasing in $\hat{\theta}_m$, $m = 1, 2$. $f(\cdot)$ is positive over the domain defined by $\hat{\theta}_m$.

4. NFB^m growth depends on the relative value of $\hat{\theta}_m$ compared to $\hat{\theta}_{-m}$:

[7] $-m$ refers to the fund manager who is not Fund Manager m.

$$NFB^m(1) = \tilde{f}(\hat{\theta}_m - \hat{\theta}_{-m}), \tag{1.2.22}$$

where $\tilde{f}(0) = nfb$ and $\tilde{f} : \mathbb{R} \to \mathbb{R}$ is a linear function increasing in $\hat{\theta}_m - \hat{\theta}_{-m}$, $m = 1, 2$. $\tilde{f}(\cdot)$ is positive over the domain defined by $\hat{\theta}_m - \hat{\theta}_{-m}$.

The risk neutral fund managers' preferences are represented by linear utility functions. A fund manager's maximization problem using a traditional fee structure is:

$$\max_{C^m(0)} MFT^m(1) + \beta \cdot \mathbb{E}_0[MFT^m(2)], \tag{1.2.23}$$

where $\beta \in (0, 1]$ is the time discount factor commonly used by fund managers $m = 1, 2$. A fund manager does not have any control over the first term, $MFT^m(1)$. The second term, $MFT^m(2)$, depends on the effect $C^m(0)$ has on $NFB^m(1)$.

A fund manager using a performance-based fee structure has a more complicated decision making process and objective function:

$$\max_{\{C^m(0), C^m(1)\}} MFP^m(1) + \mathbb{E}_0[PF^m(1)] + \beta \cdot \mathbb{E}_0[MFP^m(2) + PF^m(2)], \tag{1.2.24}$$

$m = 1, 2$. A fund manager does not have any control over the first term, $MFP^m(1)$. $PF^m(1)$ depends on the effect $C^m(0)$ has on $X^m(1)$. The second period profit depends on the investment choice in both periods. Similarly to a fund manager without performance fees, $MFP^m(2)$ depends on the effect $C^m(0)$ has on $NFB^m(1)$. A fund manager's profit from performance fees in the second period is a function of her investment choice in both periods, $C^m(0)$ and $C^m(1)$.

The two fee structures are examined under the four different fund manager evaluation metrics in Section 1.3 and Section 1.4. Appendix A.1 summarizes the eight cases.

1.2.3 Additional Return Assumptions

Conditioning only on her private signal, assume Investment R has a higher expected return when a fund manager observes S_G and Investment RL has a higher expected return when a fund manager observes S_B in the first period:

$$r_G \cdot \mathbb{P}(\omega_{G_1}|S_{G_0}) + r_B \cdot \mathbb{P}(\omega_{B_1}|S_{G_0}) > r, \tag{1.2.25}$$

$$r > r_G \cdot \mathbb{P}(\omega_{G_1}|S_{B_0}) + r_B \cdot \mathbb{P}(\omega_{G_1}|S_{B_0}). \tag{1.2.26}$$

Refer to the chosen fund manager to move first in the second period as Fund Manager l. For any values of $\hat{\theta}_1^1$, $\hat{\theta}_2^1$, $\hat{\theta}_1^2$, and $\hat{\theta}_2^2$ that are calculated using the first period equilibrium strategies presented in Section 1.3.3 to Section 1.3.10, Fund Manager l maximizes $\mathbb{E}_1[X^l(2)|S^l(1), \hat{\theta}_l^l, \hat{\theta}_{-1}^l]$ by choosing:

- $C^l(1) =$ Investment R_1^l when $S^l(1) = S_{G_1}^l$,
- $C^l(1) =$ Investment RL_1^l when $S^l(1) = S_{B_1}^l$.

Fund Manager $-l$ maximizes $\mathbb{E}_1[X^{-l}(2)|S^1(1), S^2(1), \hat{\theta}_l^{-l}, \hat{\theta}_{-l}^{-l}]$ by choosing:

- $C^{-l}(1) =$ Investment R_1^{-l} when $(S_{G_1}^1, S_{G_1}^2)$,
- $C^{-l}(1) =$ Investment R_1^{-l} when $(S_{B_1}^1, S_{G_1}^2)$,

- $C^{-l}(1) =$ Investment R_1^{-l} when $(S^1_{G_1}, S^2_{B_1})$,

- $C^{-l}(1) =$ Investment RL_1^{-l} when $(S^1_{B_1}, S^2_{B_1})$.

1.2.4 Timing of Events

Timing in the first period is as follows:

- $t = 0$:

  1. Fund Manager 1 and Fund Manager 2 are endowed with $NFB^1(0) = nfb$ and $NFB^2(0) = nfb$ respectively,
  2. Fund Manager 1 and Fund Manager 2 observe private signals $S^1(0)$ and $S^2(0)$ respectively,
  3. Fund Manager 1 chooses $C^1(0)$ based on $S^1(0)$,
  4. Fund Manager 2 chooses $C^2(0)$ based on $S^2(0)$ and $C^1(0)$.

- $t = 1$:

  1. The state of the world for the first period, $\omega(1)$, is revealed.
  2. Fund Manager 1 and Fund Manager 2 receive management fees $MFT^1(1)$ and $MFT^2(1)$ respectively if they use a traditional fee structure, and $MFP^1(1)$ and $MFP^2(1)$ respectively if they use a performance-based fee structure.
  3. Fund Manager 1 and Fund Manager 2 receive performance fees $PF^1(1)$ and $PF^2(1)$ if they use a performance-based fee structure.

4. Investors calculate a posterior probability for the ability type of each fund manager, $\hat{\theta}_m$, $m = 1, 2$.

Timing in the second period is as follows:

- $t = 1$:

1. Fund Manager 1 and Fund Manager 2 earn a net fund balance of $NFB^1(1)$ and $NFB^2(1)$ respectively, which is determined by one of the four NFB growth scenarios.
2. Fund Manager 1 and Fund Manager 2 receive private signals $S^1(1)$ and $S^2(1)$ respectively.
3. Either Fund Manager 1 or Fund Manager 2 is randomly chosen with equal probability to make the first investment. Refer to chosen fund manager as Fund Manager l.
4. Fund Manager l chooses $C^l(1)$ based on $S^l(1)$.
5. Fund Manager $-l$ chooses $C^{-l}(1)$ based on $S^{-l}(1)$ and $C^l(1)$.

- $t = 2$:

1. The state of the world for the second period, $\omega(2)$, is revealed.
2. Fund Manager 1 and Fund Manager 2 receive management fees $MFT^1(2)$ and $MFT^2(2)$ respectively if they use a traditional fee structure, and $MFP^1(2)$ and $MFP^2(2)$ respectively if they use a performance-based fee structure.

3. Fund Manager 1 and Fund Manager 2 receive performance fees $PF^1(2)$ and $PF^2(2)$ respectively if they use a performance-based fee structure.

1.3 Equilibria

1.3.1 Equilibria Introduction

Throughout this chapter, the term "efficient" strategy refers to a fund manager choosing the investment that maximizes their fund's expected return. An efficient equilibrium is an equilibrium in which both fund managers use efficient strategies.

Perfect Bayesian equilibria are subgame perfect Bayesian equilibria that include the fund managers' beliefs that are consistent with Bayes' rule. Let $\mu_1(\cdot)$ represent Fund Manager 1's beliefs and $\mu_2(\cdot)$ represent Fund Manager 2's beliefs. The same set of Bayesian consistent beliefs are used in all equilibria. Using calculations in Appendix A.3, the Bayesian consistent beliefs in the second period are:

$$\begin{aligned} \mu_l(\omega_{G_2}|S^l_{G_1},\hat{\theta}^l_l) &= 1-\mu_l(\omega_{B_2}|S^l_{G_1},\hat{\theta}^l_l) \\ &= \mathbb{P}(\omega_{G_2}|S^l_{G_1},\hat{\theta}^l_l) \\ &= \frac{1}{2}+\hat{\theta}^l_l(p-\frac{1}{2}) \quad l=1,2, \qquad (1.3.1) \\ \mu_{-l}(\omega_{G_2}|S^1_{B_1},S^2_{G_1},\hat{\theta}^{-l}_l,\hat{\theta}^{-l}_{-l}) &= 1-\mu_{-l}(\omega_{B_2}|S^1_{B_1},S^2_{G_1},\hat{\theta}^{-l}_l,\hat{\theta}^{-l}_{-l}) \\ &= \mathbb{P}(\omega_{G_2}|S^1_{B_1},S^2_{G_1},\hat{\theta}^{-l}_l,\hat{\theta}^{-l}_{-l}) \end{aligned}$$

$$= \frac{(1-p)\hat{\theta}_l(1-\hat{\theta}_{-l})+p\hat{\theta}_{-l}(1-\hat{\theta}_l)+\frac{1}{2}(1-\hat{\theta}_l)(1-\hat{\theta}_{-l})}{\hat{\theta}_l(1-\hat{\theta}_{-l})+\hat{\theta}_{-l}(1-\hat{\theta}_l)+(1-\hat{\theta}_l)(1-\hat{\theta}_{-l})}, \qquad (1.3.2)$$

$$\mu_{-l}(\omega_{G_2}|S^1_{G_1}, S^2_{B_1}, \hat{\theta}^{-l}_l, \hat{\theta}^{-l}_{-l}) = 1 - \mu_{-l}(\omega_{B_2}|S^1_{G_1}, S^2_{B_1}, \hat{\theta}^{-l}_l, \hat{\theta}^{-l}_{-l})$$
$$= \mathbb{P}(\omega_{G_2}|S^1_{G_1}, S^2_{B_1}, \hat{\theta}^{-l}_l, \hat{\theta}^{-l}_{-l})$$
$$= \frac{2p\hat{\theta}_l(1-\hat{\theta}_{-l}) + 2(1-p)\hat{\theta}_{-l}(1-\hat{\theta}_l) + (1-\hat{\theta}_l)(1-\hat{\theta}_{-l})}{2\hat{\theta}_l(1-\hat{\theta}_{-l}) + 2\hat{\theta}_{-l}(1-\hat{\theta}_l) + 2(1-\hat{\theta}_l)(1-\hat{\theta}_{-l})}, \tag{1.3.3}$$

$$\mu_{-l}(\omega_{G_2}|S^1_{B_1}, S^2_{B_1}, \hat{\theta}^{-l}_l, \hat{\theta}^{-l}_{-l}) = \mu_{-l}(\omega_{B_2}|S^1_{G_1}, S^2_{G_1}, \hat{\theta}^{-l}_l, \hat{\theta}^{-l}_{-l})$$
$$= 1 - \mu_{-l}(\omega_{B_2}|S^1_{B_1}, S^2_{B_1}, \hat{\theta}^{-l}_l, \hat{\theta}^{-l}_{-l})$$
$$= 1 - \mu_{-l}(\omega_{G_2}|S^1_{G_1}, S^2_{G_1}, \hat{\theta}^{-l}_l, \hat{\theta}^{-l}_{-l})$$
$$= \mathbb{P}(\omega_{G_2}|S^1_{B_1}, S^2_{B_1}\hat{\theta}^{-l}_l, \hat{\theta}^{-l}_{-l})$$
$$= \frac{4(1-p)\hat{\theta}_l\hat{\theta}_{-l} + 2(1-p)\hat{\theta}_l(1-\hat{\theta}_{-l}) + 2(1-p)\hat{\theta}_{-l}(1-\hat{\theta}_l) + (1-\hat{\theta}_l)(1-\hat{\theta}_{-l})}{4\hat{\theta}_l\hat{\theta}_{-l} + 2\hat{\theta}_l(1-\hat{\theta}_{-l}) + 2\hat{\theta}_{-l}(1-\hat{\theta}_l) + 2(1-\hat{\theta}_l)(1-\hat{\theta}_{-l})}, \tag{1.3.4}$$

where $-l = 1, 2$ refers to the fund manager that is chosen to pick their investment second in the second period.

$$\mu_m(T_m|S^m(0), \omega(1)) = \hat{\theta}^*_m(S^m(0), \omega(1)), \quad m = 1, 2,$$
$$\mu_m(T_m|S^1(0), S^2(0), \omega(1)) = \hat{\theta}^{**}_m(S^{-m}(0), S^m(0), \omega(1)), \quad m = 1, 2, \tag{1.3.5}$$

where $\hat{\theta}^*_m(S^m(0), \omega(1))$ and $\hat{\theta}^{**}_m(S^{-m}(0), S^m(0), \omega(1))$ are shown in Appendix A.3.

Using calculations in Appendix A.3, the Bayesian consistent beliefs in the first period are:

$$
\begin{aligned}
\mu_m(\omega_{G_1}|S^m_{G_0}) &= 1-\mu_m(\omega_{B_1}|S^m_{G_0}) \\
&= \mathbb{P}(\omega_{G_1}|S^m_{G_0}) \\
&= \frac{1}{2}+\theta(p-\frac{1}{2}), \quad m=1,2, \qquad (1.3.6) \\
\mu_2(\omega_{G_1}|S^1_{B_0},S^2_{G_0}) &= \mu_2(\omega_{G_1}|S^1_{G_0},S^2_{B_0}) \\
&= 1-\mu_2(\omega_{B_1}|S^1_{B_0},S^2_{G_0}) \\
&= 1-\mu_2(\omega_{B_1}|S^1_{G_0},S^2_{B_0}) \\
&= \mathbb{P}(\omega_{G_1}|S^1_{B_0},S^2_{G_0}) \\
&= \frac{1}{2}, \qquad (1.3.7) \\
\mu_2(\omega_{G_1}|S^1_{B_0},S^2_{B_0}) &= \mu_2(\omega_{B_1}|S^1_{G_0},S^2_{G_0}) \\
&= 1-\mu_2(\omega_{B_1}|S^1_{B_0},S^2_{B_0}) \\
&= 1-\mu_2(\omega_{G_1}|S^1_{G_0},S^2_{G_0}) \\
&= \mathbb{P}(\omega_{G_1}|S^1_{B_0},S^2_{B_0}) \\
&= \frac{4\theta(1-p)+(1-\theta)^2}{4\theta+2(1-\theta)^2}, \qquad (1.3.8)
\end{aligned}
$$

$$
\begin{aligned}
\mu_m(T_m|S^m(0)) &= \mu_m(T_{-m}|S^m(0)) \\
&= 1-\mu_m(U_m|S^m(0)) = 1-\mu_m(U_{-m}|S^m(0)) \\
&= \mu_m(T_m) = \mu_m(T_{-m}) \\
&= 1-\mu_m(U_m) = 1-\mu_m(U_{-m}) \\
&= \theta, \quad m=1,2, \qquad (1.3.9) \\
\mu_2(T_1|S^1(0)=S^2(0)) &= \mu_2(T_2|S^1(0)=S^2(0)) \\
&= 1-\mu_2(U_1|S^1(0)=S^2(0)) \\
&= 1-\mu_2(U_2|S^1(0)=S^2(0)) \\
&= \frac{\theta(1+\theta)}{1+\theta^2}, \quad m=1,2, \qquad (1.3.10) \\
\mu_2(T_2|S^1(0)\neq S^2(0)) &= \mu_2(T_2|S^1(0)\neq S^2(0)) \\
&= 1-\mu_2(U_1|S^1(0)\neq S^2(0)) \\
&= 1-\mu_2(U_2|S^1(0)\neq S^2(0)) \\
&= \frac{\theta}{1+\theta}, \quad m=1,2. \qquad (1.3.11)
\end{aligned}
$$

The equilibrium strategies in each period must form a perfect Bayesian equilibrium because the model has a finite time horizon. The equilibrium strategies in the second period are unique[8]. Therefore, equilibrium strategies in the first period can be solved without regarding the equilibrium strategies in the second period. Backwards induction is used to solve for pure strategy perfect Bayesian equilibria.

[8]The equilibrium beliefs in the second period regarding fund manager talent are not unique, but the equilibrium strategies are the same for all equilibrium beliefs.

Section 1.3.2 presents the strategies in the second period for the eight different cases that differ by fee structure and fund manager evaluation metric. Section 1.3.3 through Section 1.3.10 review the strategies in the first period and present the overall equilibria under the eight different cases. Section 1.4 summarizes the results for the eight cases and details of calculations are in Appendix A.3.

1.3.2 Second Period for All Cases

The investment strategy in the second period is identical for all eight cases that differ by fee structure and fund manager evaluation metric. There are no reputation concerns under either fee structure because there are no future periods to attract investors. Thus, a fund manager using performance fees has the sole objective of maximizing the fund return in the second period. The investment choice in the second period is arbitrary for a fund manager without performance fees, but it is assumed that a fund manager indifferent between two investments will choose the efficient investment. Therefore, the objective for both fund managers in all eight cases is to maximize the expected return in the second period. Let l denote the fund manager who is randomly chosen to invest first in the second period.

Theorem 1. *In the second period, Fund Manager l will choose the investment that matches her private signal in the second period. Specifically, $C^l(1) =$ Investment R_1^l if $S^l(1) = S^l_{G_1}$ and $C^l(1) =$ Investment RL_1^l if $S^l(1) = S^l_{B_1}$. Conditioning on $C^l(1)$, Fund Manager $-l$ will choose $C^{-l}(1) =$ Investment RL_1^{-l}*

if $C^l(1) =$ *Investment* RL_1^l *and* $S^{-l}(1) = S_{B_1}^{-l}$*, and* $C^{-l}(1) =$ *Investment* R_1^{-l} *otherwise. The fund managers' Bayesian consistent beliefs are presented in Section 1.3.1.*

Proof. In the second period, Fund Manager l's investment decision is solely based on her private signal because she chooses first. Using the assumptions in Section 1.2.3, $C^l(1) =$ Investment R_1^l if $S^1(1) = S_{G_1}^l$ and $C^l(1) =$ Investment RL_1^l if $S^l(1) = S_{B_1}^l$.

Although Fund Manager $-l$ does not directly observe $S^l(1)$, she can infer the private signal from $C^l(1)$ because of the one-to-one mapping from private signals to investment choices for Fund Manager l. Consider the case in which $S^{-l}(1) = S_{B_1}^{-l}$ and $C^l(l) =$ Investment R_1^l. Fund Manager $-l$ will base $C^{-l}(1)$ on the two-signal information set $(S_{G_1}^l, S_{B_1}^{-l})$. Therefore, $C^{-l}(1) =$ Investment R_1^{-l} because of the assumptions in Section 1.2.3. Similarly, $C^{-l}(1) =$ Investment R_1^{-l} when Fund Manager $-l$ conditions on the information set $(S_{B_1}^l, S_{G_1}^{-l})$. Using the assumptions in Section 1.2.3, $C^{-l}(1) =$ Investment R_1^{-l} when the information set is $(S_{G_1}^l, S_{G_1}^{-l})$ and $C^{-l}(1) =$ Investment RL_1^{-l} when the information set is $(S_{B_1}^l, S_{B_1}^{-l})$. □

1.3.3 Case 1: Traditional Fee Structure and NFB^m Growth Depends Only on $X^m(1)$

As shown in Section 1.2.2, a fund manager's maximization problem using a traditional fee structure is:

$$\max_{C^m(0)} MFT^m(1) + \beta \cdot \mathbb{E}_0[MFT^m(2)], \tag{1.3.12}$$

where $\beta \in (0, 1]$ is the time discount factor commonly used by fund managers $m = 1, 2$.

NFB growth depends only on $X^m(1)$:

$$NFB^m(1) = g\big(X^m(1)\big), \tag{1.3.13}$$

where $g : \mathbb{R} \to \mathbb{R}$ is a linear function increasing in $X^m(1)$, $m = 1, 2$. $g(\cdot)$ is positive over the domain defined by $X^m(1)$.

It is clear from (1.3.12) and (1.3.13) that each fund manager's sole objective in the first period is to maximize her expected fund return.

Theorem 2. *Under the assumptions in Case 1, there exists a perfect Bayesian equilibrium in which Fund Manager 1 will choose the investment that matches her private signal in the first period. Specifically, $C^1(0) =$ Investment R_0^1 if $S^1(0) = S_{G_0}^1$ and $C^1(0) =$ Investment RL_0^1 if $S^1(0) = S_{B_0}^1$. Conditioning on $C^1(0)$, Fund Manager 2 will choose $C^2(0) =$ Investment RL_0^2 if $C^1(0) =$ Investment RL_0^1 and $S^2(0) = S_{B_0}^2$, and $C^2(0) =$ Investment R_0^2 otherwise. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. In the first period, Fund Manager 1's investment decision is solely based on her private signal because she chooses first. Using probability calculations in Appendix A.3.1 and assumptions shown in (1.2.25) and (1.2.26), it is clear that $C^1(0) =$ Investment R_0^1 if $S^1(0) = S_{G_0}^1$ and $C^1(0) =$ Investment RL_0^1 if $S^1(0) = S_{B_0}^1$.

Although Fund Manager 2 does not directly observe $S^1(0)$, she can infer the private signal from $C^1(0)$ because of the one-to-one mapping from private signals to investment choices for Fund Manager 1. Consider the case in which $S^2(0) = S^2_{B_0}$ and $C^1(0) =$ Investment R^1_0. Fund Manager 2 will base $C^2(0)$ on the two-signal information set $(S^1_{G_0}, S^2_{B_0})$. Calculation (A.3.11) in Appendix A.3.2 shows the two states are equally likely to happen when conditioning on the information set $(S^1_{G_0}, S^2_{B_0})$. Therefore, $C^2(0) =$ Investment R^2_0 because of the assumption stated in (1.2.8). $C^2(0)$ in Case 1 does not depend on the order of information arrival; Fund Manager 2 treats the information sets $(S^1_{G_0}, S^2_{B_0})$ and $(S^1_{B_0}, S^2_{G_0})$ the same. Therefore, $C^2(0) =$ Investment R^2_0 when Fund Manager 2 conditions on the information set $(S^1_{B_0}, S^2_{G_0})$. Using calculations in Appendix A.3.2, $C^2(0) =$ Investment R^2_0 when the information set is $(S^1_{G_0}, S^2_{G_0})$ and $C^2(0) =$ Investment RL^2_0 when the information set is $(S^1_{B_0}, S^2_{B_0})$.

Theorem 1 completes the proof. $\square$

A larger θ means a fund manager has a better chance of being a smart fund manager, and a larger p means the signals that smart managers receive are more informative. Therefore, in Case 1, fund managers' expected utility is increasing with respect to p and θ. Because Fund Manager 2 is able to use a two signal information set when making her decision in the first period, her expected utility is higher than Fund Manager 1.

1.3.4 Case 2: Performance-Based Fee Structure and NFB^m Growth Depends Only on $X^m(1)$

As shown in Section 1.2.2, a fund manager's maximization problem using a performance-based fee structure is:

$$\max_{\{C^m(0),C^m(1)\}} MFP^m(1) + \mathbb{E}_0[PF^m(1)] + \beta \cdot \mathbb{E}_0[MFP^m(2) + PF^m(2)], \quad (1.3.14)$$

where $\beta \in (0, 1]$ is the time discount factor commonly used by fund managers $m = 1, 2$.

NFB growth depends only on $X^m(1)$:

$$NFB^m(1) = g\big(X^m(1)\big), \quad (1.3.15)$$

where $g : \mathbb{R} \to \mathbb{R}$ is a linear function increasing in $X^m(1)$, $m = 1, 2$. $g(\cdot)$ is positive over the domain defined by $X^m(1)$.

It is clear from (1.3.14) and (1.3.15) that the sole objective of each fund manager is to maximize their expected fund return in the first period.

Theorem 3. *Under the assumptions in Case 2, there exists a perfect Bayesian equilibrium in which Fund Manager 1 will choose the investment that matches her private signal in the first period. Specifically,* $C^1(0) =$ *Investment* R_0^1 *if* $S^1(0) = S^1_{G_0}$ *and* $C^1(0) =$ *Investment* RL_0^1 *if* $S^1(0) = S^1_{B_0}$*. Conditioning on* $C^1(0)$*, Fund Manager 2 will choose* $C^2(0) =$ *Investment* RL_0^2 *if* $C^1(0) =$ *Investment* RL_0^1 *and* $S^2(0) = S^2_{B_0}$*, and* $C^2(0) =$ *Investment* R_0^2 *otherwise. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. The proof for Theorem 3 is the same as the proof for Theorem 2 in Section 1.3.3. $\square$

1.3.5 Case 3: Traditional Fee Structure and NFB^m Growth Depends on the Relative Value of $X^m(1)$ Compared to $X^{-m}(1)$

As shown in Section 1.2.2, a fund manager's maximization problem using a traditional fee structure is:

$$\max_{C^m(0)} MFT^m(1) + \beta \cdot \mathbb{E}_0[MFT^m(2)], \tag{1.3.16}$$

where $\beta \in (0, 1]$ is the time discount factor commonly used by fund managers $m = 1, 2$.

NFB growth depends on the relative value of $X^m(1)$ compared to $X^{-m}(1)$:

$$NFB^m(1) = \tilde{g}\big(X^m(1) - X^{-m}(1)\big), \tag{1.3.17}$$

where $\tilde{g}(0) = nfb$, and $\tilde{g} : \mathbb{R} \to \mathbb{R}$ is linear function increasing in $X^m(1) - X^{-m}(1)$, $m = 1, 2$. $\tilde{g}(\cdot)$ is positive over the domain defined by $X^m(1) - X^{-m}(1)$.

It is clear from (1.3.16) and (1.3.17) that the sole objective of each fund manager is to maximize $\mathbb{E}[X^m(1) - X^{-m}(1)]$.

Lemma 1. *Under the assumptions in Case 3, Fund Manager 2 will invest efficiently in the first period regardless of Fund Manager 1's strategy.*

Proof. Fund Manager 1 chooses her investment before observing $C^2(0)$, therefore Fund Manager 2's investment decision can only affect $X^2(1)$. Fund Manager 2 will maximize $\mathbb{E}[X^2(1)]$ in order to maximize $\mathbb{E}[X^2(1) - X^1(1)]$. $\square$

Lemma 2. *Under the assumptions in Case 3 and given Fund Manager 2 will invest efficiently, Fund Manager 1 will not invest efficiently in the first period.*

Proof. Lemma 1 shows Fund Manager 2 will choose $C^2(0) = \text{Investment } RL_0^2$ if $C^1(0) = \text{Investment } RL_0^1$ and $S^2(0) = S^2_{B_0}$, and $C^2(0) = \text{Investment } R_0^2$ otherwise.

Consider the case in which $S^1(0) = S^1_{G_0}$. In order for Fund Manager 1 to invest efficiently, the following condition must hold:

$$\begin{aligned} & (r_G - r_G) \cdot \mathbb{P}(\omega_{G_1}|S^1_{G_0}) + (r_B - r_B) \cdot \mathbb{P}(\omega_{B_1}|S^1_{G_0}) \\ \geq \quad & (r - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{G_0}) + (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{G_0}) \\ + \quad & (r - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{G_0}) + (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{G_0}). \end{aligned} \tag{1.3.18}$$

The left-hand side of condition (1.3.18) is the expected difference in fund returns when both fund managers invest efficiently. The right-hand side of condition (1.3.18) is the expected difference in fund returns when Fund Manager 1 deviates from the efficient equilibrium. Using calculations in Appendix A.3.1, condition (1.3.18) can be reduced to:

$$\begin{aligned} & r_G \cdot [\theta p + \frac{1}{4}(1-\theta)^2] + r_B \cdot [\theta(1-p) + \frac{1}{4}(1-\theta)^2] \\ \geq \quad & r \cdot [\theta + \frac{1}{2}(1-\theta)^2]. \end{aligned} \tag{1.3.19}$$

Given assumptions (1.2.8) and $p > .5$, condition (1.3.18) is always satisfied.

Now consider the case in which $S^1(0) = S^1_{B_0}$. In order for Fund Manager 1 to invest efficiently, the following condition must hold:

$$
\begin{aligned}
& (r - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{B_0}) + (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{B_0}) \\
+ \quad & (r - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{B_0}) + (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{B_0}) \\
\geq \quad & (r_G - r_G) \cdot \mathbb{P}(\omega_{G_1} | S^1_{B_0}) + (r_B - r_B) \cdot \mathbb{P}(\omega_{B_1} | S^1_{B_0}).
\end{aligned} \tag{1.3.20}
$$

The left-hand side of condition (1.3.20) is the expected difference in fund returns when both fund managers invest efficiently. The right-hand side of condition (1.3.20) is the expected difference in fund returns when Fund Manager 1 deviates from the efficient equilibrium. Using calculations in Appendix A.3.1, condition (1.3.20) can be reduced to:

$$r \geq \frac{1}{2} \cdot r_G + \frac{1}{2} \cdot r_B. \tag{1.3.21}$$

Condition (1.3.21) is a direct violation of assumption (1.2.8), therefore condition (1.3.20) is never satisfied and Fund Manager 1 will deviate from the efficient investment strategy. $\square$

Lemma 3. *Under the assumptions in Case 3 and given Fund Manager 2 invests efficiently, Fund Manager 1 will not follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment RL^1_0 if others assume Fund Manager 1 observed $S^1(0) = S^1_{G_0}$ when she deviates with $C^1(0) =$ Investment R^1_0. Similarly, Fund Manager 1 will not follow a strategy in the first period in which* *she always chooses* $C^1(0) =$ *Investment* R_0^1 *if* $\pi\frac{1-\theta}{\theta} < r - r_G(1-p) - r_B p$ *and others assume Fund Manager 1 observed* $S^1(0) = S^1_{B_0}$ *when she deviates with* $C^1(0) =$ *Investment* RL_0^1*. On the other hand, Fund Manager 1 will follow a strategy in the first period in which she always chooses* $C^1(0) =$ *Investment* R_0^1 *if* $\pi\frac{1-\theta}{\theta} \geq r - r_G(1-p) - r_B p$ *and others assume Fund Manager 1 observed* $S^1(0) = S^1_{B_0}$ *when she deviates with* $C^1(0) =$ *Investment* RL_0^1*.*

Proof. When Fund Manager 1 ignores her signal, Fund Manager 2 learns nothing from $C^1(0)$. Therefore, Fund Manager 2 will choose the investment that matches her private signal in the first period. Specifically, $C^2(0) =$ Investment R_0^2 if $S^2(0) = S^2_{G_0}$ and $C^2(0) =$ Investment RL_0^2 if $S^2(0) = S^2_{B_0}$.

Consider the strategy in which Fund Manager 1 always chooses $C^1(0) =$ Investment RL_0^1. Fund Manager 1 will follow this strategy only if the following two conditions are satisfied:

$$\begin{aligned}
& && (r - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{G_0}) + (r - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{G_0}) \\
& + && (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{G_0}) + (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{G_0}) \\
\geq & && (r_G - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{G_0}) + (r_B - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{G_0}) \\
& + && (r_G - r_G) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{G_0}) \\
& + && (r_B - r_B) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{G_0}), \qquad (1.3.22)
\end{aligned}$$

$$
\begin{aligned}
& (r - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{B_0}) + (r - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{B_0}) \\
+ \quad & (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{B_0}) + (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{B_0}) \\
\geq \quad & (r_G - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{B_0}) + (r_B - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{B_0}) \\
+ \quad & (r_G - r_G) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{B_0}) \\
+ \quad & (r_B - r_B) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{B_0}). \qquad (1.3.23)
\end{aligned}
$$

Condition (1.3.22) is the relevant condition when $S^1(0) = S^1_{G_0}$ and condition (1.3.23) is the relevant condition when $S^1(0) = S^1_{B_0}$. Using calculations in Appendix A.3.1, condition (1.3.22) can be reduced to:

$$
\begin{aligned}
& r \cdot [\theta + \frac{1}{2}(1-\theta)^2] \\
\geq \quad & r_G \cdot [\theta p + \frac{1}{4}(1-\theta)^2] + r_B \cdot [\theta(1-p) + \frac{1}{4}(1-\theta)^2]. \qquad (1.3.24)
\end{aligned}
$$

Given assumptions (1.2.8) and $p > .5$, condition (1.3.22) is never satisfied. Using calculations in Appendix A.3.1, condition (1.3.23) can be reduced to:

$$
r \geq r_G + r_B. \qquad (1.3.25)
$$

Given assumption (1.2.8), condition (1.3.23) is never satisfied. Therefore, Fund Manager 1 will not follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment RL^1_0 if others assume Fund Manager 1 observed $S^1(0) = S^1_{G_0}$ when she deviates with $C^1(0) =$ Investment R^1_0.

Now consider the strategy in which Fund Manager 1 always chooses $C^1(0) =$ Investment R^1_0. Fund Manager 1 will follow this strategy only if the following two conditions are satisfied:

$$
\begin{aligned}
& (r_G - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{G_0}) + (r_B - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{G_0}) \\
+ \quad & (r_G - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{G_0}) + (r_B - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{G_0}) \\
\geq \quad & (r - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{G_0}) + (r - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{G_0}) \\
+ \quad & (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{G_0}) + (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{G_0}), \qquad (1.3.26)
\end{aligned}
$$

$$
\begin{aligned}
& (r_G - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{B_0}) + (r_B - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{B_0}) \\
+ \quad & (r_G - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{B_0}) + (r_B - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{B_0}) \\
\geq \quad & (r - r_G) \cdot \mathbb{P}(S^2_{G_0}, \omega_{G_1} | S^1_{B_0}) + (r - r_B) \cdot \mathbb{P}(S^2_{G_0}, \omega_{B_1} | S^1_{B_0}) \\
+ \quad & (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{G_1} | S^1_{B_0}) + (r - r) \cdot \mathbb{P}(S^2_{B_0}, \omega_{B_1} | S^1_{B_0}). \qquad (1.3.27)
\end{aligned}
$$

Condition (1.3.26) is the relevant condition when $S^1(0) = S^1_{G_0}$ and condition (1.3.27) is the relevant condition when $S^1(0) = S^1_{B_0}$. Using calculations in Appendix A.3.1, condition (1.3.26) can be reduced to:

$$
\begin{aligned}
& r_G \cdot [\theta p + \frac{1}{4}(1-\theta)^2 + \frac{1}{4}(1-\theta^2)] \\
+ \quad & r_B \cdot [\theta(1-p) + \frac{1}{4}(1-\theta)^2 + \frac{1}{4}(1-\theta^2)] \\
& \geq r \cdot [\theta + \frac{1}{2}(1-\theta)^2 + \frac{1}{2}(1-\theta^2)]. \qquad (1.3.28)
\end{aligned}
$$

Given assumptions (1.2.8) and $p > .5$, condition (1.3.26) is always satisfied. Using calculations in Appendix A.3.1 and definition $\frac{1}{2} \cdot r_G + \frac{1}{2} \cdot r_B = r + \pi$, condition (1.3.27) can be reduced to:

$$\begin{aligned}
& r_G \cdot [\theta(1-p) + \frac{1}{4}(1-\theta)^2 + \frac{1}{4}(1-\theta^2)] \\
+ \quad & r_B \cdot [\theta p + \frac{1}{4}(1-\theta)^2 + \frac{1}{4}(1-\theta^2)] \\
\geq \quad & r \cdot [\theta + \frac{1}{2}(1-\theta)^2 + \frac{1}{2}(1-\theta^2)] \\
\Rightarrow \quad & \pi\frac{1-\theta}{\theta} \geq r - r_G(1-p) - r_B p. \qquad (1.3.29)
\end{aligned}$$

The right-hand side of condition (1.3.29) can be positive or negative depending on the values of r, r_G, r_B, and p. As p approaches 0.5 in the limit from above, $r - r_G(1-p) - r_B p$ is certainly negative because of assumption (1.2.8). If $r - r_G(1-p) - r_B p \leq 0$, condition (1.3.29) is always satisfied because the left-hand side is always positive. If $r - r_G(1-p) - r_B p > 0$, condition (1.3.29) may or may not be satisfied depending on the values of r, r_G, r_B, p, and θ. □

Theorem 4. *Under the assumptions in Case 3, there does not exist a pure strategy perfect Bayesian equilibrium if* $\pi\frac{1-\theta}{\theta} < r - r_G(1-p) - r_B p$.

Proof. Section 1.3.1 shows the fund managers' Bayesian consistent beliefs. Combining Lemma 1, Lemma 2, and Lemma 3 directly leads to Theorem 4. □

Theorem 5. *Under the assumptions in Case 3, there exists a perfect Bayesian equilibrium in which Fund Manager 2 will invest efficiently in the first period* *and Fund Manager 1 will follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment R_0^1 if others assume Fund Manager 1 observed $S^1(0) = S_{B_0}^1$ when she deviates with $C^1(0) =$ Investment RL_0^1 and $\pi\frac{1-\theta}{\theta} \geq r - r_G(1-p) - r_B p$. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Combining Lemma 1, Lemma 2, Lemma 3, and Theorem 1 directly leads to Theorem 5. □

1.3.6 Case 4: Performance-Based Fee Structure and NFB^m Growth Depends on the Relative Value of $X^m(1)$ Compared to $X^{-m}(1)$

As shown in Section 1.2.2, a fund manager's maximization problem using a performance-based fee structure is:

$$\max_{\{C^m(0),C^m(1)\}} MFP^m(1) + \mathbb{E}_0[PF^m(1)] + \beta \cdot \mathbb{E}_0[MFP^m(2) + PF^m(2)], \quad (1.3.30)$$

where $\beta \in (0, 1]$ is the time discount factor commonly used by fund managers $m = 1, 2$.

NFB growth depends on the relative value of $X^m(1)$ compared to $X^{-m}(1)$:

$$NFB^m(1) = \tilde{g}\big(X^m(1) - X^{-m}(1)\big), \quad (1.3.31)$$

where $\tilde{g}(0) = nfb$, and $\tilde{g} : \mathbb{R} \to \mathbb{R}$ is linear function increasing in $X^m(1) - X^{-m}(1)$. $\tilde{g}(\cdot)$ is positive over the domain defined by $X^m(1) - X^{-m}(1)$.

Lemma 4. *Under the assumptions in Case 4, Fund Manager 2 will invest efficiently in the first period regardless of Fund Manager 1's strategy.*

Proof. Fund Manager 1 chooses her investment before observing $C^2(0)$, therefore Fund Manager 2's investment decision can only affect $X^2(1)$. Fund Manager 2 will maximize $\mathbb{E}[X^2(1)]$ in order to maximize $\mathbb{E}[X^2(1) - X^1(1)]$ and $PF^2(0)$. $\square$

Define new variables for Theorem 6 and Theorem 8.

- $\zeta \equiv \frac{1}{4}(1-\theta^2)(2r - r_G - r_B)$,
- $\phi_r \equiv r\Big[nfb - \frac{1}{8}\beta[nfb - \tilde{g}(\zeta)] \cdot (3+\theta^2)\Big]$,
- $\phi_G \equiv r_G\Big[[\frac{1}{2} + \theta(\frac{1}{2} - p)]nfb + \frac{1}{16}\beta[nfb - \tilde{g}(\zeta)] \cdot \big[5 + 8\theta(p - \frac{1}{2}) - \theta^2\big]\Big]$,
- $\phi_B \equiv r_B\Big[[\frac{1}{2} + \theta(p - \frac{1}{2})]nfb + \frac{1}{16}\beta[nfb - \tilde{g}(\zeta)] \cdot \big[5 - 8\theta(p - \frac{1}{2}) - \theta^2\big]\Big]$.

Theorem 6. *Under the assumptions in Case 4, there exists a perfect Bayesian equilibrium in which both fund managers invest efficiently in the first period if* $\phi_r - \phi_G - \phi_B > 0$ *and* $\frac{PFR}{MFRP} \geq \frac{\beta[nfb - \tilde{g}(\zeta)]}{\phi_r - \phi_G - \phi_B}$. *Specifically,* $C^1(0) =$ *Investment* R_0^1 *if* $S^1(0) = S^1_{G_0}$ *and* $C^1(0) =$ *Investment* RL_0^1 *if* $S^1(0) = S^1_{B_0}$. *Conditioning on* $C^1(0)$, *Fund Manager 2 will choose* $C^2(0) =$ *Investment* RL_0^2 *if* $C^1(0) =$ *Investment* RL_0^1 *and* $S^2(0) = S^2_{B_0}$, *and* $C^2(0) =$ *Investment* R_0^2 *otherwise. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Lemma 4 shows Fund Manager 1 will invest efficiently regardless of Fund Manager 1's strategy. If there is a one-to-one mapping between $S^1(0)$ and $C^1(0)$, Fund Manager 2 will choose $C^2(0) =$ Investment RL_0^2 if $C^1(0) =$ Investment RL_0^1 and $S^2(0) = S_{B_0}^2$, and $C^2(0) =$ Investment R_0^2 otherwise.

Consider the case in which $S^1(0) = S_{G_0}^1$. Without performance fees, condition (1.3.18) was shown to hold in Case 3. Case 4 differs from Case 3 by including performance fees. Performance fees are maximized by choosing efficient investments, therefore Fund Manager 1 will still invest efficiently and there will be a one-to-one mapping between $S^1(0)$ and $C^1(0)$ when $S^1(0) = S_{G_0}^1$.

Now consider the case in which $S^1(0) = S_{B_0}^1$. Using condition (1.3.20) and calculations in Appendix A.3.1, Fund Manager 1 will invest efficiently if

$$\begin{aligned} & PFR \cdot [(r - r_G)\mathbb{P}(\omega_{G_1}|S_{B_0}^1) + (r - r_B)\mathbb{P}(\omega_{B_1}|S_{B_0}^1)] \cdot nfb \\ \geq \quad & \beta[nfb - \tilde{g}(\zeta)]\big[MFRP + PFR \cdot \mathbb{E}_0[X^1(2)|S_{B_0}^1]\big]. \end{aligned} \tag{1.3.32}$$

The left-hand side of condition (1.3.32) is the expected increase in performance fees gained by Fund Manager 1 by investing efficiently. The right-hand side of condition (1.3.32) is the discounted expected profit forfeited in the second period due to investing efficiently. Refer to Appendix A.3.4 for details on calculating $\mathbb{E}_0[X^1(2)|S_{B_0}^1]$. It is clear that condition (1.3.32) will not be satisfied if $\phi_r - \phi_G - \phi_B \leq 0$. If $\phi_r - \phi_G - \phi_B > 0$, Fund Manager 1 will follow the strategy in Theorem 6 if $\frac{PFR}{MFRP} \geq \frac{\beta[nfb - \tilde{g}(\zeta)]}{\phi_r - \phi_G - \phi_B}$. $\square$

Theorem 1 completes the proof. $\square$

Lemma 5. *Under the assumptions in Case 4 and given Fund Manager 2 invests efficiently, Fund Manager 1 will not follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment RL_0^1 if others assume Fund Manager 1 observed $S^1(0) = S_{G_0}^1$ when she deviates with $C^1(0) =$ Investment R_0^1.*

Proof. Lemma 3 shows that Fund Manager 1 will not follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment RL_0^1 if others assume Fund Manager 1 observed $S^1(0) = S_{G_0}^1$ when she deviates with $C^1(0) =$ Investment R_0^1 under the assumptions in Case 3. Case 4 has the same assumptions as Case 3 with the addition of performance fees which increase the desire to invest efficiently. Therefore, Fund Manager 1 will not follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment RL_0^1 if others assume Fund Manager 1 observed $S^1(0) = S_{G_0}^1$ when she deviates with $C^1(0) =$ Investment R_0^1 under the assumptions in Case 4. $\square$

Define new variables for Lemma 6, Theorem 7, and Theorem 8.

- $\grave{\zeta}_a \equiv r_G\big[\theta(1-p) + \frac{1}{4}(1-\theta)^2\big] + r_B\big[\theta p + \frac{1}{4}(1-\theta)^2\big] - r\big[\theta + \frac{1}{2}(1-\theta)^2\big]$,
- $\grave{\zeta}_b \equiv r\big[\frac{1}{2}(1-\theta^2)\big] - (r_G + r_B)\big[\frac{1}{4}(1-\theta^2)\big]$,
- $\grave{\phi}_r \equiv r\Big[nfb - \frac{1}{8}\beta[\tilde{g}(\grave{\zeta}_a) - \tilde{g}(\grave{\zeta}_b)] \cdot (3+\theta^2)\Big]$,
- $\grave{\phi}_G \equiv r_G\Big[[\frac{1}{2} + \theta(\frac{1}{2} - p)]nfb + \frac{1}{16}\beta[\tilde{g}(\grave{\zeta}_a) - \tilde{g}(\grave{\zeta}_b)] \cdot \big[5 + 8\theta(p - \frac{1}{2}) - \theta^2\big]\Big]$,

- $\grave{\phi}_B \equiv r_B\Big[[\frac{1}{2}+\theta(p-\frac{1}{2})]nfb + \frac{1}{16}\beta[\tilde{g}(\grave{\zeta}_a)-\tilde{g}(\grave{\zeta}_b)]\cdot\big[5-8\theta(p-\frac{1}{2})-\theta^2\big]\Big]$.

Lemma 6. *Under the assumptions in Case 4 and given Fund Manager 2 invests efficiently, Fund Manager 1 will follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment R_0^1 if $\pi\frac{1-\theta}{\theta} \geq r - r_G(1-p) - r_B p$, $\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B \leq 0$ or $\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B > 0$ and $\frac{PFR}{MFRP} \leq \frac{\beta[\tilde{g}(\grave{\zeta}_a)-\tilde{g}(\grave{\zeta}_b)]}{\grave{\phi}_r-\grave{\phi}_G-\grave{\phi}_B}$, and others assume Fund Manager 1 observed $S^1(0) = S_{B_0}^1$ when she deviates with $C^1(0) =$ Investment RL_0^1.*

Proof. Lemma 3 shows that Fund Manager 1 will follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment R_0^1 if $\pi\frac{1-\theta}{\theta} \geq r - r_G(1-p) - r_B p$ and others assume Fund Manager 1 observed $S^1(0) = S_{B_0}^1$ when she deviates with $C^1(0) =$ Investment RL_0^1 in Case 3. Case 4 has the same assumptions as Case 3 with the addition of performance fees which increase the desire to invest efficiently. There is a conflict between maximizing $\mathbb{E}[X^1(0)]$ and maximizing $\mathbb{E}[X^1(0) - X^2(0)]$ only when $S^1(0) = S_{B_0}^1$. Using condition 1.3.27, Fund Manager 1 will not follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment R_0^1 if others assume Fund Manager 1 observed $S^1(0) = S_{B_0}^1$ when she deviates with $C^1(0) =$ Investment RL_0^1 if:

$$\begin{aligned} & PFR\cdot[(r-r_G)\mathbb{P}(\omega_{G_1}|S_{B_0}^1) + (r-r_B)\mathbb{P}(\omega_{B_1}|S_{B_0}^1)]\cdot nfb \\ > \quad & \beta[\tilde{g}(\grave{\zeta}_a)-\tilde{g}(\grave{\zeta}_b)]\big[MFRP + PFR\cdot\mathbb{E}_0[X^1(2)|S_{B_0}^1]\big]. \end{aligned} \tag{1.3.33}$$

The left-hand side of condition (1.3.33) is the expected increase in performance fees gained by Fund Manager 1 investing efficiently. The right-hand side of condition (1.3.33) is the discounted expected profit forfeited in the second period due to investing efficiently. Refer to Appendix A.3.4 for details on calculating $\mathbb{E}_0[X^1(2)|S^1_{B_0}]$. Given $\pi\frac{1-\theta}{\theta} \geq r - r_G(1-p) - r_B p$, Fund Manager 1 will follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment R^1_0 if $\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B \leq 0$. If $\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B > 0$, Fund Manager 1 will follow a strategy in the first period in which she always chooses $C^1(0) =$ Investment R^1_0 if $\frac{PFR}{MFRP} \leq \frac{\beta[\tilde{g}(\grave{\zeta}_a) - \tilde{g}(\grave{\zeta}_b)]}{\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B}$. □

Theorem 7. *Under the assumptions in Case 4, there exists a perfect Bayesian equilibrium in which Fund Manager 2 invests efficiently and Fund Manager 1 will follow a strategy in the first period in which she always chooses* $C^1(0) =$ *Investment* R^1_0 *if* $\pi\frac{1-\theta}{\theta} \geq r - r_G(1-p) - r_B p$, $\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B \leq 0$ *or* $\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B > 0$ *and* $\frac{PFR}{MFRP} \leq \frac{\beta[\tilde{g}(\grave{\zeta}_a) - \tilde{g}(\grave{\zeta}_b)]}{\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B}$, *and others assume Fund Manager 1 observed* $S^1(0) = S^1_{B_0}$ *when she deviates with* $C^1(0) =$ *Investment* RL^1_0*. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Combining Lemma 4, Lemma 6, and Theorem 1 leads to Theorem 7. □

Theorem 8. *Under the assumptions in Case 4, there does not exist a pure strategy equilibrium in the first period if* $\pi\frac{1-\theta}{\theta} < r - r_G(1-p) - r_B p$ *and* $\frac{PFR}{MFRP} < \frac{\beta[nfb - \tilde{g}(\zeta)]}{\phi_r - \phi_G - \phi_B}$*. If* $\pi\frac{1-\theta}{\theta} \geq r - r_G(1-p) - r_B p$*, there does not exist a pure strategy equilibrium in the first period if* $\frac{\beta[\tilde{g}(\grave{\zeta}_a) - \tilde{g}(\grave{\zeta}_b)]}{\grave{\phi}_r - \grave{\phi}_G - \grave{\phi}_B} < \frac{PFR}{MFRP} < \frac{\beta[nfb - \tilde{g}(\zeta)]}{\phi_r - \phi_G - \phi_B}$.

Proof. Section 1.3.1 shows the fund managers' Bayesian consistent beliefs. Combining Lemma 4, Lemma 5, and the proof for Lemma 6 leads to Theorem 8. □

1.3.7 Case 5: Traditional Fee Structure and NFB^m Growth Depends Only on $\hat{\theta}_m$

As shown in Section 1.2.2, a fund manager's maximization problem using a traditional fee structure is:

$$\max_{C^m(0)} MFT^m(1) + \beta \cdot \mathbb{E}_0[MFT^m(2)], \tag{1.3.34}$$

where $\beta \in (0, 1]$ is the time discount factor commonly used by fund managers $m = 1, 2$.

NFB growth depends only on $\hat{\theta}_m$:

$$NFB^m(1) = f(\hat{\theta}_m), \tag{1.3.35}$$

where $f(\theta) = nfb$ and $f : (0, 1) \to \mathbb{R}$ is a linear function increasing in $\hat{\theta}_m$, $m = 1, 2$. $f(\cdot)$ is positive over the domain defined by $\hat{\theta}_m$.

It is clear from (1.3.34) and (1.3.35) that in absence of a performance fee, a fund manager's only focus in the first period is to be considered talented by maximizing $\mathbb{E}[\hat{\theta}_m]$.

Lemma 7. *Under the assumptions in Case 5 and given Fund Manager 1 invests efficiently, there does not exist an equilibrium in the first period in which Fund Manager 2's investment choice depends on her private signal.*

Proof. Lemma 7 is proved using proof by contradiction. Assume there exists an equilibrium in which Fund Manager 2 uses $S^2(0)$ when choosing $C^2(0)$. Although investors only observe Fund Manager 2's investment choice, there is a one-to-one mapping from private signals to investment choices for at least one conditioning case when Fund Manager 2 uses her signal. For instance, consider the efficient strategy from Section 1.3.3. Although there is not a one-to-one mapping for Fund Manager 2's signals to investment choices when conditioning on $C^1(0) =$ Investment R_0^1, there is a one-to-one mapping when conditioning on $C^1(0) =$ Investment RL_0^1. For any strategy such that there is not at least one one-to-one mapping from Fund Manager 2's signals to investment choices when conditioning on $C^1(0)$, it is clear that Fund Manager 2 is not using her signal.

Consider the case in which $C^1(0) =$ Investment RL_0^1 and Fund Manager 2 and investors infer $S^1(0) = S_{B_0}^1$. In order for Fund Manager 2 to follow a strategy that has a one-to-one mapping from private signals to investment choices, the following must be true:

$$\begin{aligned} & \hat{\theta}_2^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{B_0}^1, S_{B_0}^2) \\ + \; & \hat{\theta}_2^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{B_0}^1, S_{B_0}^2) \\ \geq \; & \hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{B_0}^1, S_{B_0}^2) \\ + \; & \hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{B_0}^1, S_{B_0}^2), \end{aligned} \tag{1.3.36}$$

$$
\begin{aligned}
& \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{G_0}) \\
+ \quad & \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{G_0}) \\
\geq \quad & \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{G_0}) \\
+ \quad & \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{G_0}). \qquad (1.3.37)
\end{aligned}
$$

Condition (1.3.36) is associated with $S^2(0) = S^2_{B_0}$ and condition (1.3.37) is associated with $S^2(0) = S^2_{G_0}$. The left-hand side of conditions (1.3.36) and (1.3.37) is the expected posterior probability of being the talented type that Fund Manager 2 obtains by following a strategy with a one-to-one mapping from private signals to investment choices. The right-hand side of conditions (1.3.36) and (1.3.37) is the expected posterior probability of being the talented type that Fund Manager 2 obtains by tricking others into thinking she received a different signal.

Using calculations in Appendix A.3.2, condition (1.3.36) is shown to hold, but (1.3.37) is shown to be violated[9]. The intuition behind Fund Manager 2 deviating when $C^1(0) =$ Investment RL^1_0 is signals are perfectly correlated when both fund managers are talented. Therefore, by choosing a different investment than Fund Manager 1, Fund Manager 2 rules out the possibility that both fund managers are talented. The fact that condition (1.3.37) is never satisfied means there does not exist an equilibrium in which Fund Manager 2

[9]Conditions (1.3.36) and (1.3.37) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

follows a strategy that has a one-to-one mapping between private signals and investment choices when conditioning on $C^1(0) =$ Investment RL_0^1.

Although condition (1.3.37) is never satisfied, it is useful to see how the condition depends on p and θ. Not surprisingly, condition (1.3.37) is closer to being satisfied as θ becomes smaller. If $\theta = 0$, then Fund Manager 2's posterior probability of being smart will be zero regardless of $C^2(0)$. Condition (1.3.37) is closer to being satisfied as p becomes larger. If $p = 1$, then condition (1.3.37) would be satisfied because the posterior probability that Fund Manager 1 is smart is zero if Fund Manager 2 does not herd and is correct about the state of the world. Thus, Fund Manager 2 is not penalized for ruling out the possibility that both fund managers are the smart type when $p = 1$.

Now suppose $C^1(0) =$ Investment R_0^1, and therefore Fund Manager 2 and investors can infer $S^1(0) = S_{G_0}^1$. In order for Fund Manager 2 to follow a strategy that has a one-to-one mapping from private signals to investment choices, the following must be true:

$$\begin{aligned} & \hat{\theta}_2^{**}(S_{G_0}^1, S_{B_0}^2, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{G_0}^1, S_{B_0}^2) \\ + & \hat{\theta}_2^{**}(S_{G_0}^1, S_{B_0}^2, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{G_0}^1, S_{B_0}^2) \\ \geq & \hat{\theta}_2^{**}(S_{G_0}^1, S_{G_0}^2, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{G_0}^1, S_{B_0}^2) \\ + & \hat{\theta}_2^{**}(S_{G_0}^1, S_{G_0}^2, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{G_0}^1, S_{B_0}^2), \end{aligned} \tag{1.3.38}$$

$$
\begin{aligned}
& \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{G_0}) \\
+ \quad & \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{G_0}) \\
\geq \quad & \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{G_0}) \\
+ \quad & \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{G_0}). \qquad (1.3.39)
\end{aligned}
$$

Condition (1.3.38) is associated with $S^2(0) = S^2_{B_0}$ and condition (1.3.39) is associated with $S^2(0) = S^2_{G_0}$. Using calculations in Appendix A.3.2, condition (1.3.39) is shown to hold, but (1.3.38) is shown to be violated[10]. The fact that condition (1.3.38) is never satisfied means there does not exist an equilibrium in which Fund Manager 2 follows a strategy that has a one-to-one mapping between private signals and investment choices when conditioning on $C^1(0) =$ Investment R^1_0. Similarly to condition (1.3.37), condition (1.3.36) is closer to being satisfied as p becomes larger and θ becomes smaller.

Given a one-to-one mapping between $S^1(0)$ and $C^1(0)$, there does not exist a strategy for Fund Manager 2 in which she has a one-to-one mapping between private signals and investment choices because condition (1.3.38) and condition (1.3.37) are always violated. This implies there does not exist an equilibrium in the first period in which Fund Manager 2's investment choice depends on her private signal. □

[10] Conditions (1.3.38) and (1.3.39) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

Lemma 8. *Under the assumptions in Case 5 and given Fund Manager 1 invests efficiently, there exists an equilibrium in the first period in which Fund Manager 2 always mimics Fund Manager 1 if others assume* $S^2(0) = S^2_{G_0}$ *when Fund Manager 2 deviates from the herding equilibrium with* $C^2(0) =$ *Investment* R^2_0 *and assume* $S^2(0) = S^2_{B_0}$ *when Fund Manager 2 deviates with* $C^2(0) =$ *Investment* RL^2_0.

Proof. If Fund Manager 2 mimics Fund Manager 1 and chooses $C^2(0) = C^1(0)$ regardless of $S^2(0)$, investors' revised skill assessment for Fund Manager 2 is simply $\hat{\theta}_2 = \theta$. There is no Bayesian updating because Fund Manager 2 ignores $S^2(0)$ in the herding equilibrium.

Consider the case in which $C^1(0) =$ Investment RL^1_0. In order for Fund Manager 2 not to deviate from the herding equilibrium when $C^1(0) =$ Investment RL^1_0 and $S^2(0) = S^2_{B_0}$, the following must be true:

$$\begin{aligned}\theta \;\; \geq \;\; & \hat{\theta}^{**}_2(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{B_0}) \\ & + \hat{\theta}^{**}_2(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{B_0}). \qquad (1.3.40)\end{aligned}$$

Condition (1.3.40) uses the assumption in Lemma 8 that Fund Manager 1 and investors assume $S^2(0) = S^2_{G_0}$ when $C^1(0) =$ Investment RL^1_0 and Fund Manager 2 deviates from the herding equilibrium. Calculations in Appendix A.3.2 show condition (1.3.40) is always satisfied[11].

[11] Condition (1.3.40) was evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

In order for Fund Manager 2 not to deviate from the herding equilibrium when $C^1(0) =$ Investment RL_0^1 and $S^2(0) = S_{G_0}^2$, the following must be true:

$$\begin{aligned}\theta \quad &\geq \quad \hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{B_0}^1, S_{G_0}^2) \\ &\quad +\hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{B_0}^1, S_{G_0}^2). \end{aligned} \tag{1.3.41}$$

Calculations in Appendix A.3.2 reduce inequality (1.3.41) to:

$$\theta \geq \frac{\theta}{1+\theta}, \tag{1.3.42}$$

which is always satisfied.

Although condition (1.3.40) and condition (1.3.41) are always satisfied, they are both satisfied to a larger degree with a larger θ. Condition (1.3.40) is satisfied to a larger degree with a larger p, while condition (1.3.41) does not depend on p.

Now consider the case in which $C^1(0) =$ Investment R_0^1. In order for Fund Manager 2 not to deviate from the herding equilibrium when $S^2(0) = S_{G_0}^2$, the following must be true:

$$\begin{aligned}\theta \quad &\geq \quad \hat{\theta}_2^{**}(S_{G_0}^1, S_{B_0}^2, \omega_{A_1})\mathbb{P}(\omega_{G_1}|S_{G_0}^1, S_{G_0}^2) \\ &\quad +\hat{\theta}_2^{**}(S_{G_0}^1, S_{B_0}^2, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{G_0}^1, S_{G_0}^2). \end{aligned} \tag{1.3.43}$$

Calculations in Appendix A.3.2 show inequality (1.3.43) is satisfied[12].

[12]Condition (1.3.43) was evaluated over a grid for $\theta \in (0,1)$ and $p \in (.5,1)$ using steps of .001.

In order for Fund Manager 2 not to deviate from the herding equilibrium when $C^1(0) =$ Investment R_0^1 and $S^2(0) = S_{B_0}^2$, the following must be true:

$$\begin{aligned} \theta \geq & \hat{\theta}_2^{**}(S_{G_0}^1, S_{B_0}^2, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{G_0}^1, S_{B_0}^2) \\ & +\hat{\theta}_2^{**}(S_{G_0}^1, S_{B_0}^2, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{G_0}^1, S_{B_0}^2). \end{aligned} \quad (1.3.44)$$

Calculations in Appendix A.3.2 show inequality (1.3.44) is satisfied[13].

Although condition (1.3.43) and condition (1.3.44) are always satisfied, they are both satisfied to a larger degree with a larger θ. Condition (1.3.43) is satisfied to a larger degree with a larger p, while condition (1.3.44) does not depend on p. $\square$

Lemma 9. *Under the assumptions in Case 5, Fund Manager 1 is willing to invest efficiently in the first period if Fund Manager 2 mimics Fund Manager 1's investment choice in the first period. Specifically, $C^1(0) =$ Investment R_0^1 if $S^1(0) = S_{G_0}^1$, and $C^1(0) =$ Investment RL_0^1 if $S^1(0) = S_{B_0}^1$.*

Proof. If Fund Manager 2 mimics Fund Manager 1's investment choice, there is no information learned by investors observing Fund Manager 2's investment choice in the first period. Therefore, Fund Manager 1's revised skill prior, $\hat{\theta}_1^*$, is only a function of her private signal and the realized state of the world. The strategy for Fund Manager 1 described in Lemma 9 has a one-to-one mapping between private signals and investment choices. Therefore, investors can infer the private signal Fund Manager 1 observed given her investment choice.

[13]Condition (1.3.44) was evaluated over a grid for $\theta \in (0,1)$ and $p \in (.5,1)$ using steps of .001.

In order for Fund Manager 1 to choose the investment corresponding to her private signal, the following two conditions must be satisfied:

$$\begin{aligned}
& \hat{\theta}_1^*(S^1_{G_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{G_0}) + \hat{\theta}_1^*(S^1_{G_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{G_0}) \\
\geq \; & \hat{\theta}_1^*(S^1_{B_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{G_0}) + \hat{\theta}_1^*(S^1_{B_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{G_0}), \qquad (1.3.45) \\
& \hat{\theta}_1^*(S^1_{B_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{B_0}) + \hat{\theta}_1^*(S^1_{B_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{B_0}) \\
\geq \; & \hat{\theta}_1^*(S^1_{G_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{B_0}) + \hat{\theta}_1^*(S^1_{G_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{B_0}). \qquad (1.3.46)
\end{aligned}$$

Condition (1.3.45) is associated with $S^1(0) = S^1_{G_0}$ and condition (1.3.46) is associated with $S^1(0) = S^1_{B_0}$. The left-hand side of condition (1.3.45) and condition (1.3.46) is the expected posterior probability Fund Manager 1 obtains by following a strategy that allows investors to correctly infer her private signal. The right-hand side of conditions (1.3.45) and (1.3.46) is the expected posterior probability Fund Manager 1 obtains by trying to trick others into thinking she received a different signal.

Using calculations in Appendix A.3.1, it is found that condition (1.3.45) condition and (1.3.46) are always satisfied[14]. Therefore, Fund Manager 1's actions are consistent with the strategy described in Lemma 9. □

Theorem 9. *Under the assumptions in Case 5, there exists a perfect Bayesian equilibrium in which the first period strategies are Fund Manager 1 choosing* $C^1(0) =$ *Investment* R^1_0 *if* $S^1(0) = S^1_{G_0}$ *and choosing* $C^1(0) =$ *Investment* RL^1_0

[14]Conditions (1.3.45) and (1.3.46) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

if she observes $S^1(0) = S^1_{B_0}$, while Fund Manager 2 always mimics Fund Manager 1's investment choice regardless of her private signal. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.

Proof. Combining Lemma 7, Lemma 8, Lemma 9, and Theorem 1 directly leads to Theorem 9. □

Lemma 10. *Under the assumptions in Case 5 and given Fund Manager 1 ignores her signal and always chooses $C^1(0)$ = Investment R^2_0 or always chooses $C^1(0)$ = Investment RL^2_0 in the first period, Fund Manager 2 will invest efficiently in the first period. More specifically, $C^2(0)$ = Investment R^2_0 if $S^2(0) = S^2_{G_0}$ and $C^2(0)$ = Investment RL^2_0 if $S^2(0) = S^2_{B_0}$.*

Proof. Fund Manager 2 simply maximizes $\mathbb{E}[\hat{\theta}^*_2]$ because Fund Manager 1 ignores her signal and always earns $\hat{\theta}_1 = \theta$ regardless of $C^2(0)$. Therefore, the proof for Lemma 10 follows the same arguments as the proof for Lemma 9. □

Lemma 11. *Under the assumptions in Case 5 and given Fund Manager 2 invests efficiently, Fund Manager 1 is willing to ignore her signal and always choose $C^1(0)$ = Investment R^2_0 or always choose $C^1(0)$ = Investment RL^2_0 in the first period if others assume Fund Manager 1 observed $S^1(0) = S^1_{B_0}$ if she deviates with $C^1(0)$ = Investment RL^1_0 and Fund Manager 1 observed $S^1(0) = S^1_{G_0}$ if she deviates with $C^1(0)$ = Investment R^1_0.*

Proof. First consider the case in which Fund Manager 1 always chooses $C^1(0) =$ Investment R_0^2. In order for Fund Manager 1 not to deviate from this strategy, the following conditions must hold:

$$\begin{aligned}\theta \geq\ & \hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_0})\mathbb{P}(S_{G_0}^2, \omega_{G_0}|S_{G_0}^1) \\ & +\hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_0})\mathbb{P}(S_{G_0}^2, \omega_{B_0}|S_{G_0}^1) \\ & +\hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_0})\mathbb{P}(S_{B_0}^2, \omega_{G_0}|S_{G_0}^1) \\ & +\hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_0})\mathbb{P}(S_{B_0}^2, \omega_{B_0}|S_{G_0}^1), \end{aligned} \tag{1.3.47}$$

$$\begin{aligned}\theta \geq\ & \hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_0})\mathbb{P}(S_{G_0}^2, \omega_{G_0}|S_{B_0}^1) \\ & +\hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_0})\mathbb{P}(S_{G_0}^2, \omega_{B_0}|S_{B_0}^1) \\ & +\hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_0})\mathbb{P}(S_{B_0}^2, \omega_{G_0}|S_{B_0}^1) \\ & +\hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_0})\mathbb{P}(S_{B_0}^2, \omega_{B_0}|S_{B_0}^1). \end{aligned} \tag{1.3.48}$$

Condition (1.3.47) is associated with $S^1(0) = S_{G_0}^1$ and condition (1.3.48) is associated with $S^1(0) = S_{B_0}^1$. Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.47) and condition (1.3.48) are always satisfied[15].

Although condition (1.3.47) is always satisfied, it is satisfied to a larger degree with a larger θ and smaller p. On the other hand, condition (1.3.48) does not depend on p and has a non-monotonic relationship with respect to θ.

[15]Conditions (1.3.47) and (1.3.48) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

Now consider the case in which Fund Manager 1 always chooses $C^1(0) =$ Investment RL_0^2. In order for Fund Manager 1 not to deviate from this strategy, the following conditions must hold:

$$\theta \geq \hat{\theta}_1^*(S_{G_0}^1, \omega_{G_0})\mathbb{P}(\omega_{G_0}|S_{G_0}^1) + \hat{\theta}_1^*(S_{G_0}^1, \omega_{B_0})\mathbb{P}(\omega_{B_0}|S_{G_0}^1), \tag{1.3.49}$$

$$\theta \geq \hat{\theta}_1^*(S_{G_0}^1, \omega_{G_0})\mathbb{P}(\omega_{G_0}|S_{B_0}^1) + \hat{\theta}_1^*(S_{G_0}^1, \omega_{B_0})\mathbb{P}(\omega_{B_0}|S_{B_0}^1). \tag{1.3.50}$$

Condition (1.3.49) is associated with $S^1(0) = S_{G_0}^1$ and condition (1.3.50) is associated with $S^1(0) = S_{B_0}^1$. Using calculations in Appendix A.3.1, it is found that condition (1.3.49) and condition (1.3.50) are always satisfied[16].

Condition (1.3.49) is independent of θ and p. Although condition (1.3.50) is always satisfied, it is satisfied to a larger degree with a larger θ and larger p. □

Theorem 10. *Under the assumptions in Case 5, there exists a perfect Bayesian equilibrium in which the strategies in the first period are Fund Manager 1 ignoring her signal and always chooses $C^1(0) =$ Investment R_0^2 or always chooses $C^1(0) =$ Investment RL_0^2, and Fund Manager 2 investing efficiently. More specifically, $C^2(0) =$ Investment R_0^2 if $S^2(0) = S_{G_0}^2$ and $C^2(0) =$ Investment RL_0^2 if $S^2(0) = S_{B_0}^2$. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

[16]Conditions (1.3.49) and (1.3.50) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

Proof. Combining Lemma 10, Lemma 11, and Theorem 1 directly leads to Theorem 10. □

1.3.8 Case 6: Performance-Based Fee Structure and NFB^m Growth Depends Only on $\hat{\theta}_m$

As shown in Section 1.2.2, a fund manager's maximization problem using a performance-based fee structure is:

$$\max_{\{C^m(0),C^m(1)\}} MFP^m(1)+\mathbb{E}_0[PF^m(1)]+\beta\cdot\mathbb{E}_0[MFP^m(2)+PF^m(2)], \quad (1.3.51)$$

where $\beta \in (0,1]$ is the time discount factor commonly used by fund managers $m=1,2$.

NFB growth depends only on $\hat{\theta}_m$:

$$NFB^m(1)=f(\hat{\theta}_m), \quad (1.3.52)$$

where $f(\theta)=nfb$ and $f:(0,1)\to\mathbb{R}$ is a linear function increasing in $\hat{\theta}_m$, $m=1,2$. $f(\cdot)$ is positive over the domain defined by $\hat{\theta}_m$.

Unlike Case 5, a fund manager using a performance-based fee structure does not have the sole objective of being considered talented when choosing an investment in the first period if the NFB growth depends only on $\hat{\theta}_m$. A fund manager using a performance-based fee structure may forfeit some profit in the second period if there is a large increase in expected $PF^m(1)$ by choosing a different investment than the one that maximizes expected $\hat{\theta}_m$.

Lemma 12. *Under the assumptions in Case 6, Fund Manager 1 will invest efficiently if Fund Manager 2 mimics Fund Manager 1's investment choice* *in the first period. Specifically,* $C^1(0) =$ *Investment* R_0^1 *if* $S^1(0) = S_{G_0}^1$*, and* $C^1(0) =$ *Investment* RL_0^1 *if* $S^1(0) = S_{B_0}^1$.

Proof. Theorem 2 shows Fund Manager 1 maximizes her investment return by choosing the investment that matches her signal. Lemma 9 shows Fund Manager 1 maximizes her expected posterior probability of being talented when Fund Manager 2 mimics her investment choice by also choosing the investment that matches her signal. Therefore, there is not a conflict between these two goals. Fund Manager 1 will choose $C^1(0) =$ Investment R_0^1 if $S^1(0) = S_{G_0}^1$, and $C^1(0) =$ Investment RL_0^1 if $S^1(0) = S_{B_0}^1$. $\square$

Define new variables for Theorem 11:

- $\tilde{\phi}_r \equiv r\Big[nfb + \frac{1}{8}\beta[nfb - f(\frac{\theta}{1+\theta})] \cdot (3 + \hat{\theta}_D^{\dagger 2})\Big]$,
- $\tilde{\phi}_G \equiv r_G\Big[\frac{1}{2}nfb - \frac{1}{16}\beta[nfb - f(\frac{\theta}{1+\theta})] \cdot \big[5 + 8\hat{\theta}_D^{\dagger}(p - \frac{1}{2}) - \hat{\theta}_D^{\dagger 2}\big]\Big]$,
- $\tilde{\phi}_B \equiv r_B\Big[\frac{1}{2}nfb - \frac{1}{16}\beta[nfb - f(\frac{\theta}{1+\theta})] \cdot \big[5 - 8\hat{\theta}_D^{\dagger}(p - \frac{1}{2}) - \hat{\theta}_D^{\dagger 2}\big]\Big]$.

Theorem 11. *Under the assumptions in Case 6, there exists a perfect Bayesian equilibrium in which the Fund Manager 1 invests efficiently in the first period. Specifically,* $C^1(0) =$ *Investment* R_0^1 *if* $S^1(0) = S_{G_0}^1$*, and* $C^1(0) =$ *Investment* RL_0^1 *if* $S^1(0) = S_{B_0}^1$*. Conditioning on* $C^1(0)$*, Fund Manager 2 always mimics Fund Manager 1's investment choice in the first period regardless of her private signal if* $\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r \leq 0$ *or* $\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r > 0$ *and*

$\frac{PFR}{MFRP} < \frac{\beta[nfb - f(\frac{\theta}{1+\theta})]}{\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r}$. *Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Fund Manager 2 will deviate from the herding equilibrium described in Theorem 9 if the increase in $PF^2(1)$ by choosing a different investment than the one that maximizes expected $\hat{\theta}_2$ outweighs the expected forfeit of profit in the second period. There is a conflict between $\mathbb{E}[\hat{\theta}_2]$ and maximizing $\mathbb{E}[X^2(1)]$ when $C^1(0) =$ Investment RL^1_0 and $S^2(0) = S^2_{G_0}$. Condition (1.3.42) shows Fund Manager 2 will herd when using a traditional fee structure because $\theta \geq \frac{\theta}{1+\theta}$ is always satisfied. In contrast, Fund Manager 2 will deviate from the herding equilibrium when using a performance-based fee structure if:

$$\begin{aligned} & PFR \cdot \Big[(r_G - r)\mathbb{P}(\omega_{G_1} | S^1_{B_0}, S^2_{G_0}) \\ & +(r_B - r)\mathbb{P}(\omega_{B_1} | S^1_{B_0}, S^2_{G_0})\Big] \cdot nfb \\ \geq \; & \beta[nfb - f(\frac{\theta}{1+\theta})]\Big[MFRP \\ & +PFR \cdot \mathbb{E}_0[X^2(2) | S^1_{B_0}, S^2_{G_0}]\Big]. \end{aligned} \tag{1.3.53}$$

The left-hand side of condition (1.3.53) is the expected increase in performance fees gained by deviating from the herding equilibrium with $C^2(0) =$ Investment R^2_0. The right-hand side of condition (1.3.53) is the discounted expected profit forfeited in the second period due to reducing the expected $\hat{\theta}_2$.

Reducing $\mathbb{E}[\hat{\theta}_2]$ from θ to $\frac{\theta}{1+\theta}$ reduces $\mathbb{E}[NFB^2(1)]$ by $nfb - f(\frac{\theta}{1+\theta})$. Condition (1.3.53) uses $\geq$ rather than $>$ because it is always assumed that a fund manager will invest efficiently when indifferent. Refer to Appendix A.3.3 for details on calculating $\mathbb{E}_0[X^2(2)|S^1_{B_0}, S^2_{G_0}]$. If $\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r \leq 0$, Fund Manager 2 will not deviate from the herding equilibrium. If $\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r > 0$, condition (1.3.53) can be rewritten as:

$$\frac{PFR}{MFRP} \geq \frac{\beta[nfb - f(\frac{\theta}{1+\theta})]}{\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r}. \tag{1.3.54}$$

Inequality (1.3.54) shows the decision for Fund Manager 2 to deviate from the herding equilibrium relies on the ratio between the management fee rate and the performance fee rate.

Lemma 12 shows Fund Manager 1 will invest efficiently if Fund Manager 2 follows the herding equilibrium. Fund Manager 2 will possibly deviate from the herding equilibrium only when there is a conflict between maximizing $\mathbb{E}[X^2(1)]$ and maximizing $\mathbb{E}[\hat{\theta}_2]$. This occurs only when $C^1(0) =$ Investment RL^1_0 and $S^1(0) = S^1_{G_0}$. If $\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r \leq 0$, Fund Manager 2 will not deviate from the herding equilibrium. If $\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r > 0$, condition (1.3.54) shows the herding equilibrium will still hold if $\frac{PFR}{MFRP} < \frac{\beta[nfb - f(\frac{\theta}{1+\theta})]}{\tilde{\phi}_G + \tilde{\phi}_B - \tilde{\phi}_r}$.

Theorem 1 completes the proof. $\square$

Lemma 13. *Under the assumptions in Case 6, Fund Manager 1 invests efficiently in the first period if Fund Manager 2 invests efficiently. Specifically,*

$C^1(0)$ = *Investment* R_0^1 *if* $S^1(0) = S^1_{G_0}$, *and* $C^1(0)$ = *Investment* RL_0^1 *if* $S^1(0) = S^1_{B_0}$.

Proof. assume Fund Manager 2 will follow the efficient strategy. Specifically, Fund Manager 2 will choose $C^2(0) =$ Investment RL_0^2 if $C^1(0) =$ Investment RL_0^1 and $S^2(0) = S^2_{B_0}$, and $C^2(0) =$ Investment R_0^2 otherwise. In this strategy, there is a one-to-one mapping from Fund Manager 2's private signals to investment choices when conditioning on $C^1(0) =$ Investment RL_0^1. For Fund Manager 1 not to deviate from investing efficiently when $S^1(0) = S^1_{B_0}$, the following must hold:

$$\begin{aligned}
& \hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})\mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{B_0}) \\
+ \quad & \hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1})\mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{B_0}) \\
+ \quad & \hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})\mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{B_0}) \\
+ \quad & \hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1})\mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{B_0}) \\
\geq \quad & \hat{\theta}_1^{*}(S^1_{G_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{B_0}) + \hat{\theta}_1^{*}(S^1_{G_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{B_0}). \qquad (1.3.55)
\end{aligned}$$

The left-hand side of condition (1.3.55) is the expected posterior probability that Fund Manager 1 is talented if she invests efficiently. The right-hand side of condition (1.3.55) is the expected posterior probability that Fund Manager 1 is talented if she tries to trick others into thinking she received a different signal. If Fund Manager 1 tries to trick others into thinking she observed $S^1(0) = S^1_{G_0}$, Fund Manager 2 will no longer have a one-to-one mapping between private signals and investment choices. Therefore, $C^2(0)$ does not provide any additional information when investors believe $S^1(0) = S^1_{G_0}$. Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.55) is always satisfied[17].

For Fund Manager 1 not to deviate from investing efficiently when $S^1(0) = S^1_{G_0}$, the following must hold:

$$\begin{aligned}
& \hat{\theta}^*_1(S^1_{G_0}, \omega_{G_1})\mathbb{P}(\omega_{G_1}|S_{G_0}) + \hat{\theta}^*_1(S^1_{G_0}, \omega_{B_1})\mathbb{P}(\omega_{B_1}|S_{G_0}) \\
\geq \ & \hat{\theta}^{**}_1(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})\mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{G_0}) \\
+ \ & \hat{\theta}^{**}_1(S^1_{B_0}, S^2_{B_0}, \omega_{B_1})\mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{G_0}) \\
+ \ & \hat{\theta}^{**}_1(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})\mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{G_0}) \\
+ \ & \hat{\theta}^{**}_1(S^1_{B_0}, S^2_{B_0}, \omega_{G_1})\mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{G_0}) \qquad (1.3.56)
\end{aligned}$$

The left-hand side of condition (1.3.56) is the expected posterior probability that Fund Manager 1 is talented if she invests efficiently. The right-hand side of condition (1.3.56) is the expected posterior probability that Fund Manager 1 is talented if she tries to trick others into thinking she observed $S^1(0) = S^1_{B_0}$. It is found that condition (1.3.56) is always satisfied[18]. $\square$

[17] Condition (1.3.55) was evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

[18] Condition (1.3.56) was evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

Define new variable for Theorem 12:

- $\check{\zeta} = \frac{\theta(1-p)(1+\theta)}{4\theta(1-p)+(1-\theta)^2} + \frac{\theta p(1+\theta)}{4\theta p+(1-\theta)^2}$,
- $\check{\phi}_r \equiv r\Big[nfb + \frac{1}{8}\beta[f(\check{\zeta}) - f(\frac{\theta}{1+\theta})] \cdot (3 + \hat{\theta}_D^{\dagger 2})\Big]$,
- $\check{\phi}_G \equiv r_G\Big[\frac{1}{2}nfb - \frac{1}{16}\beta[f(\check{\zeta}) - f(\frac{\theta}{1+\theta})] \cdot \big[5 + 8\hat{\theta}_D^{\dagger}(p - \frac{1}{2}) - \hat{\theta}_D^{\dagger 2}\big]\Big]$,
- $\check{\phi}_B \equiv r_B\Big[\frac{1}{2}nfb - \frac{1}{16}\beta[f(\check{\zeta}) - f(\frac{\theta}{1+\theta})] \cdot \big[5 - 8\hat{\theta}_D^{\dagger}(p - \frac{1}{2}) - \hat{\theta}_D^{\dagger 2}\big]\Big]$.

Theorem 12. *Under the assumptions in Case 6, there exists a perfect Bayesian equilibrium in which Fund Manager 1 invests efficiently in the first period. Specifically,* $C^1(0) =$ *Investment* R_0^1 *if* $S^1(0) = S^1_{G_0}$*, and* $C^1(0) =$ *Investment* RL_0^1 *if* $S^1(0) = S^1_{B_0}$*. Conditioning on* $C^1(0)$*, Fund Manager 2 will also invest efficiently in the first period if* $\check{\phi}_G + \check{\phi}_B - \check{\phi}_r > 0$ *and* $\frac{PFR}{MFRP} \geq \frac{\beta[f(\check{\zeta}) - f(\frac{\theta}{1+\theta})]}{\check{\phi}_G + \check{\phi}_B - \check{\phi}_r}$*. Specifically, Fund Manager 2 will choose* $C^2(0) =$ *Investment* RL_0^2 *if* $C^1(0) =$ *Investment* RL_0^1 *and* $S^2(0) = S^2_{B_0}$*, and* $C^2(0) =$ *Investment* R_0^2 *otherwise. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Lemma 13 shows Fund Manager 1 will invest efficiently if Fund Manager 2 invests efficiently. Fund Manager 2 will possibly deviate from the efficient herding equilibrium only when there is a conflict between maximizing $\mathbb{E}[X^2(1)]$ and maximizing $\mathbb{E}[\hat{\theta}_2]$. This occurs only when $C^1(0) =$ Investment RL_0^1 and $S^1(0) = S^1_{G_0}$. Using calculations in Appendix A.3.2, condition (1.3.37) shows

Fund Manager 2 will deviate from the efficient equilibrium when using a traditional fee structure because $\frac{\theta}{1+\theta} \geq \check{\zeta}$ is never satisfied. In contrast, Fund Manager 2 will follow the efficient equilibrium when using a performance-based fee structure if:

$$\begin{aligned} & PFR \cdot \Big[(r_G - r)\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{G_0}) \\ & +(r_B - r)\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{G_0})\Big] \cdot nfb \\ \geq \;& \beta[f(\check{\zeta}) - f(\frac{\theta}{1+\theta})]\Big[MFRP \\ & +PFR \cdot \mathbb{E}_0[X^2(2)|S^1_{B_0}, S^2_{G_0}]\Big]. \end{aligned} \tag{1.3.57}$$

The left-hand side of condition (1.3.57) is the expected increase in performance fees gained by following the efficient equilibrium $C^2(0) =$ Investment R^2_0. The right-hand side of condition (1.3.57) is the discounted expected profit forfeited in the second period due to reducing the expected $\hat{\theta}_2$. Reducing $\mathbb{E}[\hat{\theta}_2]$ from $\check{\zeta}$ to $\frac{\theta}{1+\theta}$ reduces $\mathbb{E}[NFB^2(1)]$ by $f(\check{\zeta}) - f(\frac{\theta}{1+\theta})$. Refer to Appendix A.3.3 for details on calculating $\mathbb{E}_0[X^2(2)|S^1_{B_0}, S^2_{G_0}]$. Condition (1.3.57) can be rewritten as:

$$\frac{PFR}{MFRP} \;\geq\; \frac{\beta[f(\check{\zeta}) - f(\frac{\theta}{1+\theta})]}{\check{\phi}_G + \check{\phi}_B - \check{\phi}_r}. \tag{1.3.58}$$

Inequality (1.3.58) shows the decision for Fund Manager 2 to follow the efficient equilibrium relies on the ratio between the management fee rate and the performance fee rate.

Lemma 13 shows Fund Manager 1 will invest efficiently if Fund Manager 2 invests efficiently. Fund Manager 2 will possibly deviate from the efficient equilibrium only when there is a conflict between maximizing $\mathbb{E}[X^2(1)]$ and maximizing $\mathbb{E}[\hat{\theta}_2]$. This occurs only when $C^1(0) =$ Investment RL_0^1 and $S^1(0) = S^1_{G_0}$. Condition (1.3.58) shows the efficient equilibrium will still hold if $\check{\phi}_G + \check{\phi}_B - \check{\phi}_r$ and $\frac{PFR}{MFRP} \geq \frac{\beta[f(\check{\zeta}) - f(\frac{\theta}{1+\theta})]}{\check{\phi}_G + \check{\phi}_B - \check{\phi}_r}$.

Theorem 1 completes the proof. □

Lemma 14. *Under the assumptions in Case 6 and given Fund Manager 1 ignores her signal and always chooses $C^1(0) =$ Investment R_0^2 or always chooses $C^1(0) =$ Investment RL_0^2 in the first period, Fund Manager 2 will invest efficiently. More specifically, $C^2(0) =$ Investment R_0^2 if $S^2(0) = S^2_{G_0}$ and $C^2(0) =$ Investment RL_0^2 if $S^2(0) = S^2_{B_0}$.*

Proof. When Fund Manager 1 ignores her signal, Fund Manager 2 is only evaluated by $\mathbb{E}[\hat{\theta}_2^*]$. Lemma 9 shows the efficient strategy maximizes the posterior probability of being talented for a fund manager when the other fund manager ignores her signal. Therefore, there is not a conflict between maximizing $\mathbb{E}[\hat{\theta}_2^*]$ and maximizing $\mathbb{E}[PF^2(0)]$. Fund Manager 2 will choose $C^2(0) =$ Investment R_0^2 if $S^2(0) = S^2_{G_0}$ and $C^2(0) =$ Investment RL_0^2 if $S^2(0) = S^2_{B_0}$. □

Define new variables for Theorem 13:

- $\hat{\zeta} = (\frac{2\theta(1-p)}{1+\theta})[\frac{1}{4}(1-\theta^2)] + (\frac{2\theta p}{1+\theta})[\frac{1}{4}(1-\theta^2)] + [\frac{2\theta(1-p)(1+\theta)}{4\theta(1-p)+(1-\theta)^2}][\theta(1-p) + \frac{1}{4}(1-\theta)^2] + [\frac{2\theta p(1+\theta)}{4\theta p+(1-\theta)^2}][\theta p + \frac{1}{4}(1-\theta)^2]$,

- $\hat{\phi}_r \equiv r\Big[nfb - \frac{1}{8}\beta[nfb - f(\hat{\zeta})] \cdot (3+\theta^2)\Big]$,

- $\hat{\phi}_G \equiv r_G\Big[[\frac{1}{2} + \theta(\frac{1}{2} - p)]nfb + \frac{1}{16}\beta[nfb - f(\hat{\zeta})] \cdot \big[5 + 8\theta(p - \frac{1}{2}) - \theta^2\big]\Big]$,

- $\hat{\phi}_B \equiv r_B\Big[[\frac{1}{2} + \theta(p - \frac{1}{2})]nfb + \frac{1}{16}\beta[nfb - f(\hat{\zeta})] \cdot \big[5 - 8\theta(p - \frac{1}{2}) - \theta^2\big]\Big]$.

Theorem 13. *Under the assumptions in Case 6, there exists a perfect Bayesian equilibrium in which Fund Manager 2 invests efficiently and Fund Manager 1 is willing to ignore her signal in the first period and always choose $C^1(0) =$ Investment R_0^2 if others assume Fund Manager 1 observed $S^1(0) = S^1_{B_0}$ if she deviates with $C^1(0) =$ Investment RL_0^1 and $\hat{\phi}_r - \hat{\phi}_G - \hat{\phi}_B \leq 0$ or $\hat{\phi}_r - \hat{\phi}_G - \hat{\phi}_B > 0$ and $\frac{PFR}{MFRP} < \frac{\beta[nfb - f(\hat{\zeta})]}{\hat{\phi}_r - \hat{\phi}_G - \hat{\phi}_B}$. There does not exist an equilibrium in the first period such that Fund Manager 2 invests efficiently and Fund Manager 1 is willing to ignore her signal and always choose $C^1(0) =$ Investment RL_0^2 if others assume Fund Manager 1 observed $S^1(0) = S^1_{G_0}$ if she deviates with $C^1(0) =$ Investment R_0^1. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Lemma 14 shows Fund Manager 2 will invest efficiently if Fund Manager 1 ignores her signal.

First consider the case in which Fund Manager 1 always chooses $C^1(0) =$ Investment R_0^2. Fund Manager 1 was willing to follow this strategy in Case 5 because condition (1.3.47) and condition (1.3.48) were always satisfied. When Fund Manager 1 uses performance fees, she may deviate from this strategy to increase $\mathbb{E}[PF^1(0)]$ by choosing a different investment than the one that maximizes expected $\hat{\theta}_1$. When Fund Manager 1 always chooses $C^1(0) =$ Investment R_0^2 regardless of $S^1(0)$, there is a conflict between maximizing $\mathbb{E}[\hat{\theta}_1]$ and maximizing $\mathbb{E}[X^1(1)]$ when $S^1(0) = S^1_{B_0}$. Fund Manager 1 will deviate from always choosing $C^1(0) =$ Investment R_0^2 regardless of $S^1(0)$ if:

$$\begin{aligned} & PFR \cdot [(r - r_G)\mathbb{P}(\omega_{G_1}|S^1_{B_0}) + (r - r_B)\mathbb{P}(\omega_{B_1}|S^1_{B_0})] \cdot nfb \\ > \;& \beta[nfb - f(\hat{\zeta})]\big[MFRP + PFR \cdot \mathbb{E}_0[X^1(2)|S^1_{B_0}]\big]. \end{aligned} \tag{1.3.59}$$

The left-hand side of condition (1.3.59) is the expected increase in performance fees gained by deviating from always choosing $C^1(0) =$ Investment R_0^2 regardless of $S^1(0)$. The right-hand side of condition (1.3.59) is the discounted expected profit forfeited in the second period due to reducing $\mathbb{E}[\hat{\theta}_1]$. Refer to Appendix A.3.4 for details on calculating $\mathbb{E}_0[X^1(2)|S^1_{B_0}]$. Fund Manager 1 is willing to choose $C^1(0) =$ Investment R_0^2 regardless of $S^1(0)$ if $\hat{\phi}_r - \hat{\phi}_G - \hat{\phi}_B \leq 0$ or $\hat{\phi}_r - \hat{\phi}_G - \hat{\phi}_B > 0$ and $\frac{PFR}{MFRP} < \frac{\beta[nfb - f(\hat{\zeta})]}{\hat{\phi}_r - \hat{\phi}_G - \hat{\phi}_B}$.

Now consider the case in which Fund Manager 1 always chooses $C^1(0) =$ Investment RL_0^2. There is only a conflict of interest when $S^1(0) = S^1_{G_0}$. Condition (1.3.49) can be reduced to $0 \geq 0$, therefore deviating with $C^1(0) =$ Investment R_0^2 has no effect on $\mathbb{E}[\hat{\theta}_1]$. Therefore, Fund Manager 1 will always deviate from the strategy of always choosing $C^1(0) =$ Investment RL_0^2

regardless of $S^1(0)$.

Theorem 1 completes the proof. $\square$

1.3.9 Case 7: Traditional Fee Structure and NFB^m Growth Depends on the Relative Value of $\hat{\theta}_m$ Compared to $\hat{\theta}_{-m}$

As shown in Section 1.2.2, a fund manager's maximization problem using a traditional fee structure is:

$$\max_{C^m(0)} MFT^m(1) + \beta \cdot \mathbb{E}_0[MFT^m(2)], \tag{1.3.60}$$

where $\beta \in (0, 1]$ is the time discount factor commonly used by fund managers $m = 1, 2$.

NFB growth depends on the relative value of $\hat{\theta}_m$ compared to $\hat{\theta}_{-m}$:

$$NFB^m(1) = \tilde{f}(\hat{\theta}_m - \hat{\theta}_{-m}), \tag{1.3.61}$$

where $\tilde{f}(0) = nfb$ and $\tilde{f} : \mathbb{R} \to \mathbb{R}$ is a linear function increasing in $\hat{\theta}_m - \hat{\theta}_{-m}$, $m = 1, 2$. $\tilde{f}(\cdot)$ is positive over the domain defined by $\hat{\theta}_m - \hat{\theta}_{-m}$.

Fund managers use a traditional fee structure in Case 7, therefore each fund manager's sole objective is to maximize $\mathbb{E}[\hat{\theta}_m - \hat{\theta}_{-m}]$.

Lemma 15. *Under the assumptions in Case 7 and given Fund Manager 1 invests efficiently, there exists an equilibrium in the first period in which Fund Manager 2 also has a one-to-one mapping between $S^2(0)$ and $C^2(0)$.*

Proof. Assume Fund Manager 1 will choose the investment that matches her private signal in the first period. Specifically, $C^1(0) =$ Investment R^1_0 if $S^1(0) = S^1_{G_0}$ and $C^1(0) =$ Investment RL^1_0 if $S^1(0) = S^1_{B_0}$.

Consider the case in which $C^1(0) =$ Investment RL_0^1, therefore others infer $S^1(0) = S_{B_0}^1$. In order for Fund Manager 2 to follow a strategy that has a one-to-one mapping from private signals to investment choices, the following must be true:

$$
\begin{aligned}
& [\hat{\theta}_2^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_1}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S_{B_0}^1, S_{B_0}^2) \\
+ \quad & [\hat{\theta}_2^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_1}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S_{B_0}^1, S_{B_0}^2) \\
\geq \quad & [\hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_1}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S_{B_0}^1, S_{B_0}^2) \\
+ \quad & [\hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_1}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S_{B_0}^1, S_{B_0}^2), \quad (1.3.62)
\end{aligned}
$$

$$
\begin{aligned}
& [\hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_1}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S_{B_0}^1, S_{G_0}^2) \\
+ \quad & [\hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_1}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S_{B_0}^1, S_{G_0}^2) \\
\geq \quad & [\hat{\theta}_2^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_1}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S_{B_0}^1, S_{G_0}^2) \\
+ \quad & [\hat{\theta}_2^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_1}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S_{B_0}^1, S_{G_0}^2). \quad (1.3.63)
\end{aligned}
$$

Condition (1.3.62) is associated with $S^2(0) = S_{B_0}^2$ and condition (1.3.63) is associated with $S^2(0) = S_{G_0}^2$. The left-hand side of condition (1.3.62) and condition (1.3.63) is the expected posterior probability Fund Manager 2 obtains by following a strategy that allows investors to infer correctly her private signal. The right-hand side of condition (1.3.62) and condition (1.3.63) is the expected posterior probability Fund Manager 2 obtains by trying to trick others into thinking she observed a different signal.

Using calculations in Appendix A.3.2, condition (1.3.62) reduces to:

$$0 \geq \frac{8\theta^2[4p(1-p)-8]}{(1+\theta)[4\theta+2(1-\theta)^2]}. \tag{1.3.64}$$

Using calculations in Appendix A.3.2, condition (1.3.63) reduces to:

$$0 \geq 0. \tag{1.3.65}$$

It is clear that $\frac{8\theta^2[4p(1-p)-8]}{(1+\theta)[4\theta+2(1-\theta)^2]} < 0$, therefore both condition (1.3.62) and condition (1.3.63) are always satisfied.

Although condition (1.3.62) is always satisfied, the condition becomes closer to being unsatisfied with smaller values of θ and p. For instance, if $\theta = 0$, then Fund Manager 2 would be indifferent about their investment choice because both posterior probabilities of being smart would be zero regardless of the investment choices.

Now suppose $C^1(0)$ = Investment R_0^1, therefore others infer $S^1(0) = S_{G_0}^1$. In order for Fund Manager 2 to follow a strategy that has a one-to-one mapping from private signals to investment choices, the following must be true:

$$
\begin{aligned}
& [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{B_0}) \\
+ \quad & [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{B_0}) \\
\geq \quad & [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1})\mathbb{P}](\omega_{G_1}|S^1_{G_0}, S^2_{B_0}) \\
+ \quad & [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{B_0}), \qquad (1.3.66)
\end{aligned}
$$

$$
\begin{aligned}
& [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{G_0}) \\
+ \quad & [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{G_0}) \\
\geq \quad & [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{G_0}) \\
+ \quad & [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{G_0}). \qquad (1.3.67)
\end{aligned}
$$

Condition (1.3.66) is associated with $S^2(0) = S^2_{B_0}$ and condition (1.3.67) is associated with $S^2(0) = S^2_{G_0}$. Using calculations in Appendix A.3.2, condition (1.3.66) reduces to:

$$0 \geq 0. \qquad (1.3.68)$$

Using calculations in Appendix A.3.2, condition (1.3.67) reduces to:

$$0 \geq \frac{8\theta^2[4p(1-p) - 8]}{(1+\theta)[4\theta + 2(1-\theta)^2]}. \qquad (1.3.69)$$

It is clear that $\frac{8\theta^2[4p(1-p)-8]}{(1+\theta)[4\theta+2(1-\theta)^2]} < 0$, therefore both condition (1.3.66) and condition (1.3.67) are always satisfied. Therefore, given Fund Manager 1 invests efficiently, there does exist an equilibrium in which Fund Manager 2 has a one-to-one mapping between private signals and investment choice. □

Lemma 16. *Under the assumptions in Case 7 and given Fund Manager 1 invests efficiently, there exists an equilibrium in the first period in which Fund Manager 2 always mimics Fund Manager 1 if others believe $S^2(0) = S^2_{G_0}$ when Fund Manager 2 deviates from the herding equilibrium with $C^2(0) =$ Investment R^2_0 and believe $S^2(0) = S^2_{B_0}$ when Fund Manager 2 deviates from the herding equilibrium with $C^2(0) =$ Investment RL^2_0.*

Proof. Assume Fund Manager 1 will choose the investment that matches her private signal in the first period. Specifically, $C^1(0) =$ Investment R^1_0 if $S^1(0) = S^1_{G_0}$ and $C^1(0) =$ Investment RL^1_0 if $S^1(0) = S^1_{B_0}$.

Consider the case in which $C^1(0) =$ Investment R^1_0, therefore others infer $S^1(0) = S^1_{G_0}$. In order for Fund Manager 2 to follow the herding equilibrium, the following two conditions must hold:

$$\begin{aligned}
& [\theta - \hat{\theta}^*_1(S^1_{G_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{G_0}) + [\theta - \hat{\theta}^*_1(S^1_{G_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{G_0}) \\
\geq \; & [\hat{\theta}^{**}_2(S^1_{G_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}^{**}_1(S^1_{G_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{G_0}) \\
& + [\hat{\theta}^{**}_2(S^1_{G_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}^{**}_1(S^1_{G_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{G_0}), \qquad (1.3.70)
\end{aligned}$$

$$
\begin{aligned}
& [\theta - \hat{\theta}_1^*(S^1_{G_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{B_0}) + [\theta - \hat{\theta}_1^*(S^1_{G_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{B_0}) \\
\geq \; & [\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{G_0}, S^2_{B_0}) \\
& +[\hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{G_0}, S^2_{B_0}). \qquad (1.3.71)
\end{aligned}
$$

Condition (1.3.70) is associated with $S^2(0) = S^2_{G_0}$ and condition (1.3.71) is associated with $S^2(0) = S^2_{B_0}$. Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.70) and condition (1.3.71) are always satisfied[19].

Now suppose $C^1(0) =$ Investment RL^1_0. In order for Fund Manager 2 to follow the herding equilibrium, the following two conditions must hold:

$$
\begin{aligned}
& [\theta - \hat{\theta}_1^*(S^1_{B_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{G_0}) + [\theta - \hat{\theta}_1^*(S^1_{B_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{G_0}) \\
\geq \; & [\hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{G_0}) \\
& +[\hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{G_0}), \qquad (1.3.72)
\end{aligned}
$$

$$
\begin{aligned}
& [\theta - \hat{\theta}_1^*(S^1_{B_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{B_0}) + [\theta - \hat{\theta}_1^*(S^1_{B_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{B_0}) \\
\geq \; & [\hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{B_0}) \\
& +[\hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{B_0}). \qquad (1.3.73)
\end{aligned}
$$

[19]Conditions (1.3.70) and (1.3.71) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

Condition (1.3.72) is associated with $S^2(0) = S^2_{G_0}$ and condition (1.3.73) is associated with $S^2(0) = S^2_{B_0}$. Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.72) and condition (1.3.73) are always satisfied[20]. $\square$

Lemma 17. *Under the assumptions in Case 7 and given Fund Manager 2 has a one-to-one mapping between $C^2(0)$ and $S^2(0)$, there exists an equilibria in the first period in which Fund Manager 1's invests efficiently. Specifically, $C^1(0) =$ Investment R^1_0 if $S^1(0) = S^1_{G_0}$, and $C^1(0) =$ Investment RL^1_0 if $S^1(t) = S^1_{B_0}$.*

Proof. Assume Fund Manager 2 has a one-to-one mapping between $C^2(0)$ and $S^2(0)$. For Fund Manager 1 to invest efficiently when $S^1(0) = S^1_{G_0}$, the following must hold:

[20] Conditions (1.3.72) and (1.3.73) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

$$
\begin{aligned}
& [\hat{\theta}_1^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{G_0}) \\
+ \; & [\hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{G_0}) \\
+ \; & [\hat{\theta}_1^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{G_0}) \\
+ \; & [\hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{G_0}) \\
\geq \; & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{G_0}) \\
+ \; & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{G_0}) \\
+ \; & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{G_0}) \\
+ \; & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{G_0}). \quad (1.3.74)
\end{aligned}
$$

The left-hand side of condition (1.3.74) is the expected relative posterior probability that Fund Manager 1 is talented if she invests efficiently. The right-hand side of condition (1.3.74) is the expected relative posterior probability that Fund Manager 1 is talented if she tries to trick others into thinking she observed a different signal. Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.74) is always satisfied[21].

For Fund Manager 1 to invest efficiently when $S^1(0) = S^1_{B_0}$, the following must hold:

[21]Condition (1.3.74) was evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

$$
\begin{aligned}
& [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{B_0}) \\
\geq \quad & [\hat{\theta}_1^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{G_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{B_0}). \quad (1.3.75)
\end{aligned}
$$

The left-hand side of condition (1.3.75) is the expected relative posterior probability that Fund Manager 1 is talented if she invests efficiently. The right-hand side of condition (1.3.75) is the expected relative posterior probability that Fund Manager 1 is talented if she tries to trick others into thinking she observed a different signal. Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.75) is always satisfied[22]. □

Lemma 18. *Under the assumptions in Case 7 and given Fund Manager 2 mimics Fund Manager 1's investment choice in the first period, Fund Manager 1 is willing to invest efficiently in the first period. Specifically,* $C^1(0) =$ *Investment* R^1_0 *if* $S^1(0) = S^1_{G_0}$*, and* $C^1(0) =$ *Investment* RL^1_0 *if* $S^1(t) = S^1_{B_0}$.

[22]Condition (1.3.75) was evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

Proof. Lemma 9 shows that under the assumptions in Case 5, Fund Manager 1 will invest efficiently if Fund Manager 2 follows the herding strategy. Fund Manager 2's updated posterior probability of being talented is θ regardless of $C^1(0)$ in Lemma 18. Therefore, Fund Manager 1 invests efficiently if Fund Manager 2 mimics Fund Manager 1's investment choice in the equilibrium. $\square$

Lemma 19. *Under the assumptions in Case 7 and given that Fund Manager 2 will invest efficiently, Fund Manager 1 is willing to invest efficiently. Specifically, $C^1(0)$ = Investment R_0^1 if $S^1(0) = S^1_{G_0}$, and $C^1(0)$ = Investment RL_0^1 if $S^1(t) = S^1_{B_0}$.*

Proof. Assume Fund Manager 2 will invest efficiently. Specifically, Fund Manager 2 will choose $C^2(0) =$ Investment RL_0^2 if $C^1(0) =$ Investment RL_0^1 and $S^2(0) = S^2_{B_0}$, and $C^2(0) =$ Investment R_0^2 otherwise. In this strategy, there is a one-to-one mapping from Fund Manager 2's private signals to investment choices when conditioning on $C^1(0) =$ Investment RL_0^1. For Fund Manager 1 to invest efficiently when $S^1(0) = S^1_{B_0}$, the following must hold:

$$\begin{aligned}
& [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{B_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{B_0}) \\
\geq \quad & [\hat{\theta}_1^{*}(S^1_{G_0}, \omega_{B_1}) - \theta]\mathbb{P}(\omega_{B_1}|S_{B_0}) \\
+ \quad & [\hat{\theta}_1^{*}(S^1_{G_0}, \omega_{G_1}) - \theta]\mathbb{P}(\omega_{G_1}|S_{B_0}).
\end{aligned} \tag{1.3.76}$$

The left-hand side of condition (1.3.76) is the expected relative posterior probability that Fund Manager 1 is talented if she invests efficiently. The right-hand side of condition (1.3.76) is the expected relative posterior probability that Fund Manager 1 is talented if she tries to trick others into thinking she observed a different signal.

Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.76) is always satisfied[23].

For Fund Manager 1 to invest efficiently when $S^1(0) = S^1_{G_0}$, the following must hold:

$$
\begin{aligned}
& [\hat{\theta}_1^*(S^1_{G_0}, \omega_{G_1}) - \theta]\mathbb{P}(\omega_{G_1}|S_{G_0}) \\
+ \quad & [\hat{\theta}_1^*(S^1_{G_0}, \omega_{B_1}) - \theta]\mathbb{P}(\omega_{B_1}|S_{G_0}) \\
\geq \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{B_1})]\mathbb{P}(S^2_{G_0}, \omega_{B_1}|S^1_{G_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{B_1})]\mathbb{P}(S^2_{B_0}, \omega_{B_1}|S^1_{G_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{G_0}, \omega_{G_1})]\mathbb{P}(S^2_{G_0}, \omega_{G_1}|S^1_{G_0}) \\
+ \quad & [\hat{\theta}_1^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1}) - \hat{\theta}_2^{**}(S^1_{B_0}, S^2_{B_0}, \omega_{G_1})]\mathbb{P}(S^2_{B_0}, \omega_{G_1}|S^1_{G_0}). \quad (1.3.77)
\end{aligned}
$$

The left-hand side of condition (1.3.77) is the expected relative posterior probability that Fund Manager 1 is talented if she invests efficiently. The right-hand side of condition (1.3.77) is the expected relative posterior probability

[23]Condition (1.3.76) was evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

that Fund Manager 1 is talented if she tries to trick others into thinking she observed a different signal. Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.77) is always satisfied[24]. $\square$

Theorem 14. *Under the assumptions in Case 7, there exists a perfect Bayesian equilibrium in which Fund Manager 1 will invest efficiently in the first period. Specifically,* $C^1(0) =$ *Investment* R_0^1 *if* $S^1(0) = S^1_{G_0}$ *and* $C^1(0) =$ *Investment* RL_0^1 *if* $S^1(0) = S^1_{B_0}$*. Conditioning on* $C^1(0)$*, Fund Manager 2 will invest efficiently by choosing* $C^2(0) =$ *Investment* RL_0^2 *if* $C^1(0) =$ *Investment* RL_0^1 *and* $S^2(0) = S^2_{B_0}$*, and* $C^2(0) =$ *Investment* R_0^2 *otherwise. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Lemma 15 and Lemma 16 show Fund Manager 2 is willing to invest efficiently if there is a one-to-one mapping between $C^1(0)$ and $S^1(0)$. Lemma 19 completes the proof for Theorem 14.

Theorem 1 completes the proof. $\square$

Theorem 15. *Under the assumptions in Case 7, there exists a perfect Bayesian equilibrium in which Fund Manager 1 invests efficiently and Fund Manager 2 always mimics Fund Manager 1's investment choice in the first period regardless of her private signal if others believe* $S^2(0) = S^2_{G_0}$ *when Fund Manager*

[24]Condition (1.3.77) was evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

2 deviates from the herding equilibrium with $C^2(0)$ = Investment R_0^2 and believe $S^2(0) = S_{B_0}^2$ when Fund Manager 2 deviates from the herding equilibrium with $C^2(0)$ = Investment RL_0^2. Specifically, $C^1(0)$ = Investment $R_0^1 = C^2(0)$ if $S^1(0) = S_{G_0}^1$ and chooses $C^1(0)$ = Investment $RL_0^1 = C^2(0)$ if she observes $S^1(0) = S_{B_0}^1$. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.

Proof. Combining Lemma 16, Lemma 18, and Theorem 1 leads to Theorem 15. □

Theorem 16. *Under the assumptions in Case 7, there exists a perfect Bayesian equilibrium in which both fund managers have a one-to-one mapping between private signals and investment choices in the first period. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Combining Lemma 15, Lemma 17, and Theorem 1 leads to Theorem 16. □

Although a one-to-one mapping between private-signals and investment choices leads to the most private information exposed to the public, the investment choice for Fund Manager 2 must be inefficient in order to produce the one-to-one mapping.

Lemma 20. *Under the assumptions in Case 7 and given Fund Manager 1 ignores her signal and always chooses $C^1(0)$ = Investment R_0^2 or always* *chooses $C^1(0) =$ Investment RL_0^2 in the first period, Fund Manager 2 will invest efficiently. More specifically, $C^2(0) =$ Investment R_0^2 if $S^2(0) = S_{G_0}^2$ and $C^2(0) =$ Investment RL_0^2 if $S^2(0) = S_{B_0}^2$.*

Proof. When Fund Manager 1 ignores her signal, she always earns $\hat{\theta}_1 = \theta$ regardless of $C^2(0)$. Therefore Fund Manager 2 simply maximizes $\mathbb{E}[\hat{\theta}_2^*]$ in order to maximize $\mathbb{E}[\hat{\theta}_2 - \hat{\theta}_1]$. Therefore, the proof for Lemma 20 is the same as the proof for Lemma 9. □

Lemma 21. *Under the assumptions in Case 7 and given Fund Manager 2 invests efficiently, Fund Manager 1 is willing to ignore her signal and always choose $C^1(0) =$ Investment R_0^2 or always choose $C^1(0) =$ Investment RL_0^2 in the first period if others assume Fund Manager 1 observed $S^1(0) = S_{B_0}^1$ if she deviates with $C^1(0) =$ Investment RL_0^1 and Fund Manager 1 observed $S^1(0) = S_{G_0}^1$ if she deviates with $C^1(0) =$ Investment R_0^1.*

Proof. First consider the case in which Fund Manager 1 always chooses $C^1(0) =$ Investment R_0^2. In order for Fund Manager 1 not to deviate from this strategy, the following conditions must hold:

$$
\begin{aligned}
& [\theta - \hat{\theta}_2^*(S_{G_0}^2, \omega_{G_0})]\mathbb{P}(S_{G_0}^2, \omega_{G_0}|S_{G_0}^1) + [\theta - \hat{\theta}_2^*(S_{G_0}^2, \omega_{B_0})]\mathbb{P}(S_{G_0}^2, \omega_{B_0}|S_{G_0}^1) \\
+ \quad & [\theta - \hat{\theta}_2^*(S_{B_0}^2, \omega_{G_0})]\mathbb{P}(S_{B_0}^2, \omega_{G_0}|S_{G_0}^1) + [\theta - \hat{\theta}_2^*(S_{B_0}^2, \omega_{B_0})]\mathbb{P}(S_{B_0}^2, \omega_{B_0}|S_{G_0}^1) \\
\geq \quad & [\hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_0}) - \hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_0})]\mathbb{P}(S_{G_0}^2, \omega_{G_0}|S_{G_0}^1) \\
+ \quad & [\hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_0}) - \hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_0})]\mathbb{P}(S_{G_0}^2, \omega_{B_0}|S_{G_0}^1) \\
+ \quad & [\hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_0}) - \hat{\theta}_2^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_0})]\mathbb{P}(S_{B_0}^2, \omega_{G_0}|S_{G_0}^1) \\
+ \quad & [\hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_0}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_0})]\mathbb{P}(S_{B_0}^2, \omega_{B_0}|S_{G_0}^1),
\end{aligned} \tag{1.3.78}
$$

$$
\begin{aligned}
& [\theta - \hat{\theta}_2^*(S_{G_0}^2, \omega_{G_0})]\mathbb{P}(S_{G_0}^2, \omega_{G_0}|S_{B_0}^1) + [\theta - \hat{\theta}_2^*(S_{G_0}^2, \omega_{B_0})]\mathbb{P}(S_{G_0}^2, \omega_{B_0}|S_{B_0}^1) \\
+ \quad & [\theta - \hat{\theta}_2^*(S_{B_0}^2, \omega_{G_0})]\mathbb{P}(S_{B_0}^2, \omega_{G_0}|S_{B_0}^1) + [\theta - \hat{\theta}_2^*(S_{B_0}^2, \omega_{B_0})]\mathbb{P}(S_{B_0}^2, \omega_{B_0}|S_{B_0}^1) \\
\geq \quad & [\hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_0}) - \hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{G_0})]\mathbb{P}(S_{G_0}^2, \omega_{G_0}|S_{B_0}^1) \\
+ \quad & [\hat{\theta}_1^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_0}) - \hat{\theta}_2^{**}(S_{B_0}^1, S_{G_0}^2, \omega_{B_0})]\mathbb{P}(S_{G_0}^2, \omega_{B_0}|S_{B_0}^1) \\
+ \quad & [\hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_0}) - \hat{\theta}_2^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{G_0})]\mathbb{P}(S_{B_0}^2, \omega_{G_0}|S_{B_0}^1) \\
+ \quad & [\hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_0}) - \hat{\theta}_1^{**}(S_{B_0}^1, S_{B_0}^2, \omega_{B_0})]\mathbb{P}(S_{B_0}^2, \omega_{B_0}|S_{B_0}^1).
\end{aligned} \tag{1.3.79}
$$

Condition (1.3.78) is associated with $S^1(0) = S_{G_0}^1$ and condition (1.3.79) is associated with $S^1(0) = S_{B_0}^1$. Using calculations in Appendix A.3.1 and Appendix A.3.2, it is found that condition (1.3.78) and condition (1.3.79) are always satisfied[25].

[25]Conditions (1.3.78) and (1.3.79) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

Now consider the case in which Fund Manager 1 always chooses $C^1(0) =$ Investment RL_0^2. In order for Fund Manager 1 not to deviate from this strategy, the following conditions must hold:

$$\begin{aligned}
& [\theta - \hat{\theta}_2^*(S_{G_0}^2, \omega_{G_0})]\mathbb{P}(S_{G_0}^2, \omega_{G_0}|S_{G_0}^1) + [\theta - \hat{\theta}_2^*(S_{G_0}^2, \omega_{B_0})]\mathbb{P}(S_{G_0}^2, \omega_{B_0}|S_{G_0}^1) \\
+ \quad & [\theta - \hat{\theta}_2^*(S_{B_0}^2, \omega_{G_0})]\mathbb{P}(S_{B_0}^2, \omega_{G_0}|S_{G_0}^1) + [\theta - \hat{\theta}_2^*(S_{B_0}^2, \omega_{B_0})]\mathbb{P}(S_{B_0}^2, \omega_{B_0}|S_{G_0}^1) \\
\geq \quad & [\hat{\theta}_1^*(S_{G_0}^1, \omega_{G_0}) - \theta]\mathbb{P}(\omega_{G_0}|S_{G_0}^1) + [\hat{\theta}_1^*(S_{G_0}^1, \omega_{B_0}) - \theta]\mathbb{P}(\omega_{B_0}|S_{G_0}^1), \quad (1.3.80)
\end{aligned}$$

$$\begin{aligned}
& [\theta - \hat{\theta}_2^*(S_{G_0}^2, \omega_{G_0})]\mathbb{P}(S_{G_0}^2, \omega_{G_0}|S_{B_0}^1) + [\theta - \hat{\theta}_2^*(S_{G_0}^2, \omega_{B_0})]\mathbb{P}(S_{G_0}^2, \omega_{B_0}|S_{B_0}^1) \\
+ \quad & [\theta - \hat{\theta}_2^*(S_{B_0}^2, \omega_{G_0})]\mathbb{P}(S_{B_0}^2, \omega_{G_0}|S_{B_0}^1) + [\theta - \hat{\theta}_2^*(S_{B_0}^2, \omega_{B_0})]\mathbb{P}(S_{B_0}^2, \omega_{B_0}|S_{B_0}^1) \\
\geq \quad & [\hat{\theta}_1^*(S_{G_0}^1, \omega_{G_0}) - \theta]\mathbb{P}(\omega_{G_0}|S_{B_0}^1) + [\hat{\theta}_1^*(S_{G_0}^1, \omega_{B_0}) - \theta]\mathbb{P}(\omega_{B_0}|S_{B_0}^1). \quad (1.3.81)
\end{aligned}$$

Condition (1.3.80) is associated with $S^1(0) = S_{G_0}^1$ and condition (1.3.81) is associated with $S^1(0) = S_{B_0}^1$. Using calculations in Appendix A.3.1, it is found that condition (1.3.80) and condition (1.3.81) are always satisfied[26]. □

Theorem 17. *Under the assumptions in Case 7, there exists a perfect Bayesian equilibrium in which Fund Manager 2 invests efficiently and Fund Manager 1 ignores her signal in the first period and always chooses $C^1(0) =$ Investment R_0^2 or always chooses $C^1(0) =$ Investment RL_0^2 if others assume Fund Manager 1 observed $S^1(0) = S_{B_0}^1$ if she deviates with $C^1(0) =$ Investment RL_0^1 and Fund*

[26]Conditions (1.3.80) and (1.3.81) were evaluated over a grid for $\theta \in (0, 1)$ and $p \in (.5, 1)$ using steps of .001.

Manager 1 observed $S^1(0) = S^1_{G_0}$ if she deviates with $C^1(0) =$ Investment R^1_0. Specifically, $C^2(0) =$ Investment R^2_0 if $S^2(0) = S^2_{G_0}$ and $C^2(0) =$ Investment RL^2_0 if $S^2(0) = S^2_{B_0}$. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.

Proof. Combining Lemma 20, Lemma 21, and Theorem 1 leads to Theorem 17. □

1.3.10 Case 8: Performance-Based Fee Structure and NFB^m Growth Depends on the Relative Value of $\hat{\theta}_m$ Compared to $\hat{\theta}_{-m}$

As shown in Section 1.2.2, a fund manager's maximization problem using a performance-based fee structure is:

$$\max_{\{C^m(0),C^m(1)\}} MFP^m(1) + \mathbb{E}_0[PF^m(1)] + \beta \cdot \mathbb{E}_0[MFP^m(2) + PF^m(2)], \quad (1.3.82)$$

where $\beta \in (0, 1]$ is the time discount factor commonly used by fund managers $m = 1, 2$.

NFB growth depends on the relative value of $\hat{\theta}_m$ compared to $\hat{\theta}_{-m}$:

$$NFB^m(1) = \tilde{f}(\hat{\theta}_m - \hat{\theta}_{-m}), \quad (1.3.83)$$

where $\tilde{f}(0) = nfb$ and $\tilde{f} : \mathbb{R} \to \mathbb{R}$ is a linear function increasing in $\hat{\theta}_m - \hat{\theta}_{-m}$, $m = 1, 2$. $\tilde{f}(\cdot)$ is positive over the domain defined by $\hat{\theta}_m - \hat{\theta}_{-m}$.

Theorem 18. *Under the assumptions in Case 8, there exists a perfect Bayesian equilibrium in which Fund Manager 1 will invest efficiently in the first period. Specifically, $C^1(0) =$ Investment R^1_0 if $S^1(0) = S^1_{G_0}$ and $C^1(0) =$ Investment RL^1_0*

if $S^1(0) = S^1_{B_0}$. *Conditioning on* $C^1(0)$, *Fund Manager 2 will invest efficiently by choosing* $C^2(0) =$ *Investment* RL^2_0 *if* $C^1(0) =$ *Investment* RL^1_0 *and* $S^2(0) = S^2_{B_0}$, *and* $C^2(0) =$ *Investment* R^2_0 *otherwise. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Theorem 14 shows the efficient equilibrium was sustainable under the assumptions of Case 7. Case 8 has the same assumptions as Case 7 with the addition of performance fees which increase the desire to invest efficiently. Therefore, both fund managers are still willing to follow the efficient equilibrium under the assumptions in Case 8.

Theorem 1 completes the proof. □

Lemma 22. *Under the assumptions in Case 8, Fund Manager 1 is willing to invest efficiently in the first period if Fund Manager 2 mimics Fund Manager 1's investment choice in the first period. Specifically,* $C^1(0) =$ *Investment* $R^1_0 = C^2(0)$ *if* $S^1(0) = S^1_{G_0}$, *and* $C^1(0) =$ *Investment* RL^1_0 *if* $S^1(t) = S^1_{B_0}C^2(0)$.

Proof. Lemma 18 shows Fund Manager 1 is willing to invest efficiently in the first period if Fund Manager 2 mimics Fund Manager 1's investment choice in the equilibrium under the assumptions in Case 7. Case 8 has the same assumptions as Case 7 with the addition of performance fees which increase the desire to invest efficiently. Therefore, Fund Manager 1 is willing to invest efficiently in the first period if Fund Manager 2 mimics Fund Manager 1's investment choice in the equilibrium under the assumptions in Case 8. □

Define new variables for Theorem 19

- $\overline{\zeta} = \theta - \left[\frac{\theta(1-p)}{2\theta(1-p)+(1-\theta)} + \frac{\theta p}{2\theta p+(1-\theta)}\right]$,
- $\overline{\phi}_r \equiv r\Big[nfb + \frac{1}{8}\beta[\tilde{f}(\overline{\zeta}) - nfb] \cdot (3 + \hat{\theta}_D^{\dagger 2})\Big]$,
- $\overline{\phi}_G \equiv r_G\Big[\frac{1}{2}nfb - \frac{1}{16}\beta[\tilde{f}(\overline{\zeta}) - nfb] \cdot \big[5 + 8\hat{\theta}_D^{\dagger}(p - \frac{1}{2}) - \hat{\theta}_D^{\dagger 2}\big]\Big]$,
- $\overline{\phi}_B \equiv r_B\Big[\frac{1}{2}nfb - \frac{1}{16}\beta[\tilde{f}(\overline{\zeta}) - nfb] \cdot \big[5 - 8\hat{\theta}_D^{\dagger}(p - \frac{1}{2}) - \hat{\theta}_D^{\dagger 2}\big]\Big]$.

Theorem 19. *Under the assumptions in Case 8, there exists a perfect Bayesian equilibrium in which Fund Manager 1 invests efficiently and Fund Manager 2 mimics Fund Manager 1 in the first period if others believe $S^2(0) = S^2_{G_0}$ when Fund Manager 2 deviates from the herding equilibrium with $C^2(0) =$ Investment R^2_0 and believe $S^2(0) = S^2_{B_0}$ when Fund Manager 2 deviates with $C^2(0) =$ Investment RL^2_0 and $\overline{\phi}_G + \overline{\phi}_B - \overline{\phi}_r \leq 0$ or $\overline{\phi}_G + \overline{\phi}_B - \overline{\phi}_r > 0$ and $\frac{PFR}{MFRP} < \frac{\beta[\tilde{f}(\theta,\overline{\zeta})-nfb]}{\overline{\phi}_G+\overline{\phi}_B-\overline{\phi}_r}$. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Lemma 22 shows Fund Manager 1 is willing to invest efficiently if Fund Manager 2 mimics Fund Manager 1's investment choice. Lemma 16 shows that under the assumptions in Case 7, there exists an equilibrium in the first period in which Fund Manager 2 always mimics Fund Manager 1 if Fund Manager 1 invests efficiently. The assumptions in Case 8 only differ from the assumptions in Case 7 by the addition of performance fees, which increase the desire to invest efficiently. The only scenario where Fund Manager 2 might deviate from mimicking Fund Manager 1 is when $C^1(0)$ = Investment RL_0^1 and $S^2(0) = S^2_{G_0}$. Given $C^1(0)$ = Investment RL_0^1 and $S^2(0) = S^2_{G_0}$, Fund Manager 2 will deviate from the herding equilibria if:

$$\begin{aligned} & PFR \cdot \Big[(r_G - r)\mathbb{P}(\omega_{G_1}|S^1_{B_0}, S^2_{G_0}) + (r_B - r)\mathbb{P}(\omega_{B_1}|S^1_{B_0}, S^2_{G_0})\Big] \cdot nfb \\ > \; & \beta[\tilde{f}(\overline{\zeta}) - nfb]\big[MFRP + PFR \cdot \mathbb{E}_0[X^2(2)|S^1_{B_0}, S^2_{G_0}]\big]. \end{aligned} \tag{1.3.84}$$

The left-hand side of condition (1.3.84) is the expected increase in performance fees gained by deviating from the herding strategy with $C^2(0)$ = Investment R_0^2. The right-hand side of condition (1.3.84) is the discounted expected profit forfeited in the second period due to reducing $\mathbb{E}[\hat{\theta}_2 - \hat{\theta}_1]$ by deviating from the herding strategy. Using condition (1.3.72), deviating from the herding strategy reduces $\mathbb{E}[NFB^2(1)]$ by $\tilde{f}(\overline{\zeta}) - nfb$. Refer to Appendix A.3.3 for details on calculating $\mathbb{E}_0[X^2(2)|S^1_{B_0}, S^2_{G_0}]$. If $\overline{\phi}_G + \overline{\phi}_B - \overline{\phi}_r \leq 0$, Fund Manager 2 will not deviate from the herding strategy if $\frac{PFR}{MFRP} < \frac{\beta[\tilde{f}(\overline{\zeta}) - nfb]}{\overline{\phi}_G + \overline{\phi}_B - \overline{\phi}_r}$.

Theorem 1 completes the proof.

□

Lemma 23. *Under the assumptions in Case 8 and given Fund Manager 1 ignores her signal and always chooses $C^1(0)$ = Investment R_0^2 or always chooses $C^1(0)$ = Investment RL_0^2 in the first period, Fund Manager 2 is willing to invest efficiently. More specifically, $C^2(0)$ = Investment R_0^2 if $S^2(0) = S^2_{G_0}$ and $C^2(0)$ = Investment RL_0^2 if $S^2(0) = S^2_{B_0}$.*

Proof. Lemma 20 shows Fund Manager 2 is willing to invest efficiently if Fund Manager 1 ignores her signal under the assumptions in Case 7. Case 8 has the same assumptions as Case 7 with the addition of performance fees which increase the desire to invest efficiently. Therefore, Fund Manager 2 is willing to invest efficiently if Fund Manager 1 ignores her signal under the assumptions in Case 8. □

Define new variables for Theorem 20:

- $\acute{\zeta} = \theta - \Big[(1-\theta^2)[\frac{\theta p}{4\theta p+2(1-\theta)} + \frac{\theta(1-p)}{4\theta(1-p)+2(1-\theta)}] + \frac{2\theta(1-p)}{2\theta(1-p)+(1-\theta)}[\theta(1-p) + \frac{1}{4}(1-\theta)^2] + \frac{2\theta p}{2\theta p+(1-\theta)}[\theta p + \frac{1}{4}(1-\theta)^2]\Big]$,
- $\acute{\phi}_r \equiv r\Big[nfb - \frac{1}{8}\beta[\tilde{f}(\acute{\zeta}) - nfb] \cdot (3+\theta^2)\Big]$,
- $\acute{\phi}_G \equiv r_G\Big[[\frac{1}{2} + \theta(\frac{1}{2} - p)]nfb + \frac{1}{16}\beta[\tilde{f}(\acute{\zeta}) - nfb] \cdot \big[5 + 8\theta(p - \frac{1}{2}) - \theta^2\big]\Big]$,
- $\acute{\phi}_B \equiv r_B\Big[[\frac{1}{2} + \theta(p - \frac{1}{2})]nfb + \frac{1}{16}\beta[\tilde{f}(\acute{\zeta}) - nfb] \cdot \big[5 - 8\theta(p - \frac{1}{2}) - \theta^2\big]\Big]$.

Theorem 20. *Under the assumptions in Case 8, there exists a perfect Bayesian equilibrium in which Fund Manager 2 invests efficiently and Fund Manager 1 is willing to ignore her signal in the first period and always chooses $C^1(0) =$ Investment R_0^1 if others assume Fund Manager 1 observed $S^1(0) = S^1_{B_0}$ if she deviates and $\acute{\phi}_r - \acute{\phi}_G - \acute{\phi}_B \leq 0$ or $\acute{\phi}_r - \acute{\phi}_G - \acute{\phi}_B > 0$ and $\frac{PFR}{MFRP} < \frac{\beta[\tilde{f}(\acute{\zeta}) - nfb]}{\acute{\phi}_r - \acute{\phi}_G - \acute{\phi}_B}$. Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Lemma 23 shows Fund Manager 2 is willing to invest efficiently if Fund Manager 1 ignores her signal.

When Fund Manager 1 always chooses $C^1(0) =$ Investment R_0^1 regardless of her private signal, she does not have an incentive to deviate when $S^1(0) = S_{G_0}^1$. If $S^1(0) = S_{B_0}^1$, Fund Manager 1 will deviate from always choosing $C^1(0) =$ Investment R_0^1 if:

$$\begin{aligned} & PFR \cdot [r - r_G)\mathbb{P}(\omega_{G_1}|S_{B_0}^1) + (r - r_B)\mathbb{P}(\omega_{B_1}|S_{B_0}^1)] \cdot nfb \\ > \ & \beta[\tilde{f}(\acute{\zeta}) - nfb]\big[MFRP + PFR \cdot \mathbb{E}_0[X^1(2)|S_{B_0}^1]\big]. \end{aligned} \tag{1.3.85}$$

The left-hand side of condition (1.3.85) is the expected increase in performance fees gained by deviating from the strategy of always choosing $C^1(0) =$ Investment R_0^1 regardless of her signal. The right-hand side of condition (1.3.85) is the discounted expected profit forfeited in the second period due to reducing $\mathbb{E}[\hat{\theta}_1 - \hat{\theta}_2]$ by deviating from the strategy of always choosing $C^1(0) =$ Investment R_0^1. Using condition (1.3.79), deviating from the strategy in which Fund Manager 1 always chooses $C^1(0) =$ Investment R_0^1 reduces $\mathbb{E}[NFB^1(1)]$ by $\tilde{f}(\acute{\zeta}) - nfb$. Refer to Appendix A.3.4 for details on calculating $\mathbb{E}_0[X^1(2)|S_{B_0}^1]$. If $\acute{\phi}_r - \acute{\phi}_G - \acute{\phi}_B \leq 0$, Fund Manager 1 will not deviate from the strategy in which Fund Manager 1 always chooses $C^1(0) =$ Investment R_0^1. If $\acute{\phi}_r - \acute{\phi}_G - \acute{\phi}_B > 0$, Fund Manager 1 will not deviate from the strategy in which Fund Manager 1 always chooses $C^1(0) =$ Investment R_0^2 if $\frac{PFR}{MFRP} < \frac{\beta[\tilde{f}(\acute{\zeta}) - nfb]}{\acute{\phi}_r - \acute{\phi}_G - \acute{\phi}_B}$.

Theorem 1 completes the proof. □

Define new variables for Theorem 21:

- $\ddot{\zeta}_a = \theta - \Big[\ddot{\zeta}_a = \frac{2\theta p}{2\theta p+(1-\theta)}[\theta p + \frac{1}{4}(1-\theta)^2 + \frac{1}{4}(1-\theta^2)] + \frac{2\theta(1-p)}{2\theta(1-p)+(1-\theta)}[\theta(1-p) + \frac{1}{4}(1-\theta)^2 + \frac{1}{4}(1-\theta^2)]\Big]$,
- $\ddot{\zeta}_b = \Big[\frac{2\theta p}{2\theta p+(1-\theta)}[\frac{1}{2} + \theta(p-\frac{1}{2})] + \frac{2\theta(1-p)}{2\theta(1-p)+(1-\theta)}[\frac{1}{2} + \theta(\frac{1}{2}-p)]\Big] - \theta$,
- $\ddot{\phi}_r \equiv r\Big[nfb + \frac{1}{8}\beta[\tilde{f}(\ddot{\zeta}_a) - \tilde{f}(\ddot{\zeta}_1)] \cdot (3+\theta^2)\Big]$,
- $\ddot{\phi}_G \equiv r_G\Big[[\frac{1}{2} + \theta(p-\frac{1}{2})]nfb - \frac{1}{16}\beta[\tilde{f}(\ddot{\zeta}_a) - \tilde{f}(\ddot{\zeta}_b)] \cdot \big[5 + 8\theta(p-\frac{1}{2}) - \theta^2\big]\Big]$,
- $\ddot{\phi}_B \equiv r_B\Big[[\frac{1}{2} + \theta(\frac{1}{2}-p)]nfb - \frac{1}{16}\beta[\tilde{f}(\ddot{\zeta}_a) - \tilde{f}(\ddot{\zeta}_b)] \cdot \big[5 - 8\theta(p-\frac{1}{2}) - \theta^2\big]\Big]$.

Theorem 21. *Under the assumptions in Case 8, there exists a perfect Bayesian equilibrium in which Fund Manager 2 invests efficiently and Fund Manager 1 is willing to ignore her signal in the first period and always chooses* $C^1(0) =$ *Investment* RL_0^1 *if others assume Fund Manager 1 observed* $S^1(0) = S^1_{G_0}$ *if she deviates and* $\ddot{\phi}_G + \ddot{\phi}_B - \ddot{\phi}_r \leq 0$ *or* $\ddot{\phi}_G + \ddot{\phi}_B - \ddot{\phi}_r > 0$ *and* $\frac{PFR}{MFRP} < \frac{\beta[\tilde{f}(\ddot{\zeta}_a) - \tilde{f}(\ddot{\zeta}_b)]}{\ddot{\phi}_G + \ddot{\phi}_B - \ddot{\phi}_r}$. *Theorem 1 shows the equilibrium strategies in the second period and Section 1.3.1 shows the fund managers' Bayesian consistent beliefs.*

Proof. Lemma 23 shows Fund Manager 2 is willing to invest efficiently if Fund Manager 1 ignores her signal.

When Fund Manager 1 always chooses $C^1(0) =$ Investment RL_0^1, she does not have an incentive to deviate when $S^1(0) = S^1_{B_0}$. If $S^1(0) = S^1_{G_0}$, Fund Manager 1 will deviate from always choosing $C^1(0) =$ Investment RL_0^1 if:

$$
\begin{aligned}
& PFR \cdot [(r_G - r)\mathbb{P}(\omega_{G_1}|S^1_{G_0}) + (r_B - r)\mathbb{P}(\omega_{B_1}|S^1_{G_0})] \cdot nfb \\
> \;& \beta[\tilde{f}(\ddot{\zeta}_a) - \tilde{f}(\ddot{\zeta}_b)]\big[MFRP + PFR \cdot \mathbb{E}_0[X^1(2)|S^1_{B_0}]\big]. \qquad (1.3.86)
\end{aligned}
$$

The left-hand side of condition (1.3.86) is the expected increase in performance fees gained by deviating from the strategy of always choosing $C^1(0) =$ Investment RL^1_0 regardless of her signal. The right-hand side of condition (1.3.86) is the discounted expected profit forfeited in the second period due to reducing $\mathbb{E}[\hat{\theta}_1 - \hat{\theta}_2]$ by deviating from the strategy of always choosing $C^1(0) =$ Investment RL^1_0. Using condition (1.3.80), deviating from the strategy in which Fund Manager 1 always chooses $C^1(0) =$ Investment RL^1_0 reduces $\mathbb{E}[NFB^1(1)]$ by $\tilde{f}(\ddot{\zeta}_a) - \tilde{f}(\ddot{\zeta}_b)$. Refer to Appendix A.3.4 for details on calculating $\mathbb{E}_0[X^1(2)|S^1_{B_0}]$. If $\ddot{\phi}_G + \ddot{\phi}_B - \ddot{\phi}_r \leq 0$, Fund Manager 1 will not deviate from the strategy in which Fund Manager 1 always chooses $C^1(0) =$ Investment RL^1_0. If $\ddot{\phi}_G + \ddot{\phi}_B - \ddot{\phi}_r > 0$, Fund Manager 1 will not deviate from the strategy in which Fund Manager 1 always chooses $C^1(0) =$ Investment RL^2_0 if $\frac{PFR}{MFRP} < \frac{\beta[\tilde{f}(\ddot{\zeta}_a) - \tilde{f}(\ddot{\zeta}_b)]}{\ddot{\phi}_G + \ddot{\phi}_B - \ddot{\phi}_r}$.

Theorem 1 completes the proof. □

1.4 Discussion

1.4.1 Dependence on Fee Structure

Performance fees deter herding under all four NFB growth assumptions. Under the assumptions in Case 5 and Case 7, there exists two inefficient equilibria. In one equilibrium, Fund Manager 1 invests efficiently and Fund Manager 2 mimics Fund Manager 1's investment choice. In another equilibrium, Fund Manager 1 chooses the same investment regardless of her private signal and Fund Manager 2 invests efficiently. Case 6 and Case 8 show performance fees remove these equilibria if the ratio of the performance fee rate to management fee rate is larger than calculated thresholds.

In some circumstances, the inclusion of performance fees provide an efficient equilibrium in which there was none before. Under the assumptions in Case 3, it is shown that no pure equilibrium exists if $\pi\frac{1-\theta}{\theta} < r - r_G(1-p) - r_B p$, but Case 4 shows that both fund managers will invest efficiently when $\pi\frac{1-\theta}{\theta} < r - r_G(1-p) - r_B p$ if the ratio of the performance fee rate to management fee rate is larger than a calculated threshold. Under the assumptions in Case 5, an equilibrium does not exist in which both fund managers invest efficiently, but Case 6 again shows that both fund managers will invest efficiently if the ratio of the performance fee rate to management fee rate is larger than a calculated threshold.

1.4.2 Dependence on Fund Manager Valuation Metric

A fund manager's desire to herd is induced by being evaluated on her posterior probability of ability rather than her fund return. The assumption driving herding equilibria is talented fund managers receive correlated signals that provide information about future market returns, whereas untalented fund managers receive uncorrelated noisy signals. By choosing the same investment as Fund Manager 1, Fund Manager 2 suggests that the fund managers received the same signals and therefore have a higher probability of being talented.

The effect on equilibria of fund managers being evaluated with relative metrics depends on whether the net fund balance growth depends on fund return or posterior probability of being talented. Case 3 and Case 1 show the efficient equilibrium is removed when fund managers are evaluated on their relative fund return and fund managers use a traditional fee structure. Comparing Case 4 to Case 2, the efficient equilibrium is removed if the ratio of the performance fee rate to management fee rate is low enough when fund managers are evaluated on their relative fund return and fund managers use a performance-based fee structure.

On the other hand, Case 7 and Case 5 show an efficient equilibrium is possible when fund managers are evaluated on their relative posterior probability of being talented when fund managers use a traditional fee structure. Case 8 and Case 6 show an efficient equilibrium is possible when fund managers are evaluated on their relative posterior probability of being talented when fund managers use a performance-based fee structure.

The addition of an efficient equilibrium in Case 7 and Case 8 is driven by the fact that Fund Manager 2's investment decision has a large effect on Fund Manager 1's posterior probability of being talented. The assumption is appropriate when reviewing competition between two fund managers, but not when a fund manager competes with a large group. In a scenario where many fund managers compete, a single fund manager's investment choice would impact their personal posterior probability of being talented greatly, but would have minimal influence on the posterior probability of being talented for the other fund managers.

1.4.3 Dependence on Market Efficiency and Density of Talented Fund Managers

The most compelling case to review the effect market efficienty has on reputational herding is Case 5. Conditions (1.3.37) and (1.3.38) show Fund Manager 2 will always herd, but the desire to herd is stronger when p is smaller. When reviewing conditions for a herding equilibrium to exist, the effect of p is the opposite. Conditions (1.3.40) and (1.3.43) show a larger p allows the herding equilibrium to hold easier and conditions (1.3.41) and (1.3.44) don't depend on the value of p. Conditions supporting Fund Manager 1 ignoring her signal are not consistently dependent on p. Although the way conditions depend on p is not consistent, it is reasonable to give special attention to the conditions in which Fund Manager 2 deviates from the efficient equilibrium to herd. It is unlikely that a herding equilibrium would exist in the real world because investors would not hire a fund manager that publically ignores their private information and simply follows prior investment decisions. On the other hand, it is realistic to assume fund managers deviate from investing efficiently and herd secretly. Market efficiency is decreasing with respect to p. Therefore, one may conclude that market efficiency increases the desire to herd based on reputation concerns in cases when there are no performance fees.

In an IMF report, Eichengreen and Mathieson (1999) state,

> "... [governments] can take steps to improve the functioning of financial markets by providing them with more complete information about national financial and economic policies, intentions, and conditions. Such transparency encourages all investors, including hedge funds, to trade on fundamentals rather than to run with the herd." Eichengreen and Mathieson (1999)

Eichengreen and Mathieson (1999) suggest that better information in the stock market reduces herding. Usually people view markets with more information to be more efficient, therefore Eichengreen and Mathieson (1999) predict less herding in more efficient markets. Therefore the results in this chapter differ from the opinion in Eichengreen and Mathieson (1999).

Parameter θ is the density of talented fund managers in the stock market. Similarly to p, the effects of θ on herding differ across assumptions and conditions. The most compelling case to review the effect the density of talented fund managers has on reputational herding is Case 5. In the violated efficient equilibrium conditions (1.3.37) and (1.3.38), Fund Manager 2 has a stronger desire to herd when θ is larger. Unlike the results for p, herding conditions are also easier to satisfy when θ is larger. Conditions (1.3.36) and (1.3.39) show Fund Manager 2 is more willing to invest efficiently when Fund Manager 1 ignores her private signal with larger values of θ. Conditions supporting Fund Manager 1 ignoring her signal are not consistently dependent on θ, but this equilibrium is not likely found in the real world. Therefore, it is concluded that the tendency to herd is stronger when θ is larger in cases where there are no performance fees. Stein (2009) shows that an increasing number of sophisticated investors in the stock market may not necessarily move prices closer to fundamental values because of negative externalities. This chapter adds support to the assertion that an increasing amount of sophisticated investors in the stock market may not necessarily move prices closer to fundamental values because of the increasing desire to herd based on reputation concerns.

The dependence on p and θ in herding equilibria with performance fees depend on other parameter values. In Case 6 it is intuitive that larger values of p and θ increase the expected profit from performance fees by investing efficiently, but will also increase the expected profit from management fees by herding. Therefore, the result will depend on the distribution of investment returns.

1.5 Conclusion

This chapter examined how reputational herding between fund managers depends on the fee structure, fund manager evaluation metric, market efficiency, and density of talented fund managers. It adds to existing literature by analyzing different fee structures and fund manager evaluation metrics in the framework developed in Scharfstein and Stein (1990). Results show there are more equilibria involving herding between fund managers when net fund balance growth depends on reputation of talent rather than fund return. These inefficient equilibria are removed when the ratio of the performance fee rate to management fee rate is larger than calculated thresholds that depend on market efficiency and the density of talented fund managers. In the absence of performance fees, lower predictability of investment returns and a higher density of talented fund managers increase the desire for fund managers to deviate from efficient equilibria. The model also shows having fund managers compete against each other induces herding when net fund balance growth depends on fund returns, but removes herding equilibria when net fund balance growth depends on reputation of talent.

Although hedge funds are blamed for causing financial crises, performance-based fee structures were shown to deter herding under all four fund manager evaluation metrics. Fund manager herding has the potential to destabilize stock prices and form asset bubbles. Therefore, policy makers may want to encourage performance-based fee structures to deter fund manager herding and avoid future crises.

Chapter 2

A Study of Institutional Investor Herding by Geographic Location and Institution Type

2.1 Introduction

A group of investors trading a security in the same direction can generate upward or downward pressure on the security's price. Understanding which investors trade together and when they trade together can provide insight on stock market efficiency and whether herding destabilizes asset prices. This chapter determines what herding networks exist between institutional investors and how herding depends on stock market volatility, degree of portfolio changes, and stock size.

There are many different reasons why investors may herd. Banerjee (1992) suggests investors herd due to information cascades; investors rely heavily on the investment decisions made before them by inferring information from those decisions. Another reason investors may herd is they follow a similar investment strategy, such as the positive feedback strategy documented in Grinblatt et al. (1995). A third reason investors may herd is because of reputational considerations; fund managers may trade with the crowd to not risk failing alone and looking incompetent (see Scharfstein and Stein (1990);

Wilson (2012)).

Lakonishok et al. (1992) examine herding between money managers and find more herding within small cap stocks than large cap stocks, but in general find minimal support for herding within individual stocks. Grinblatt et al. (1995) find a higher level of herding in their dataset using the same herding measure as Lakonishok et al. (1992). Grinblatt et al. (1995) attribute most of the herding in their sample to mutual funds simultaneously using positive-feedback investment strategies.

Unlike Grinblatt et al. (1995), Sias (2004) finds little evidence of herding being caused by positive-feedback investment strategies. Sias (2004) examines herding across quarters and finds that investors' demand for a security in a given quarter is positively correlated with other investors' demand for the security in the previous quarter. Choi and Sias (2009) find the correlation between the fraction of institutional traders buying an industry this quarter and the fraction buying last quarter averages 40 percent. Choi and Sias (2009) suggest that correlated signals primarily drive institutional industry herding.

Herding by institutional investors is important to study because it can impact stock prices. Sias and Starks (2006) find institutional trading has temporary price effects attributed to liquidity effects and permanent price effects attributed to information effects. Wermers (1999) shows stocks that herds buy outperform stocks they sell by four percent during the following six months.

The purpose of this chapter is to determine what herding networks exist between institutional investors and how herding depends on stock market volatility, degree of portfolio changes, and stock size. Using quarterly holding data from 2000-2010, I find stronger herding networks between similar types of institutions compared to institutions in the same metropolitan area. Furthermore, the herding network between similar types of institutions exists across metropolitan areas. Results show institutions herd more when making major portfolio changes than when making minor portfolio changes. The difference in herding between the two types of portfolio changes is greatest for small cap stocks which exhibit the highest levels of herding under both types of portfolio changes. The relationship between market volatility and herding by institutions is also examined and do not have a strong correlation using quarterly holdings data.

Hong et al. (2005) show that mutual fund managers spread information to one another by word of mouth and are likely to herd with other mutual funds in the same city. Furthermore, the geographic location of the stocks that investors herd in is independent of the investors' geographic location. However, the results in this chapter suggest networks between institutions of the same type are stronger than networks between institutions in the same metropolitan area.

Lakonishok et al. (1992) attempt to create different investor types by sorting by assets under management. Wermers (1999) and Grinblatt et al. (1995) create subgroups of mutual funds by sorting on fund category. This chapter is the first to analyze and compare the herding of multiple types of institutions within the same study. This chapter is also the first to examine the difference in herding between major and minor portfolio changes and how herding levels are related to market volatility.

The remainder of this chapter is as follows. Section 2.2 describes the data used. Section 2.3 explains the herding measure used and how testable herding networks are formed. Section 2.4 presents the results and Section 2.5 concludes the chapter.

2.2 Data

The data used are institutional quarterly long position holdings from 2000 through 2010 in the FactSet LionShares Ownership Database. The data was obtained through a custom data request by The University of Texas at Austin and includes data for non-surviving institutions that are not available using a FactSet Terminal. FactSet's primary data source are 13F filings which are mandated by the SEC for any investment management institution managing $100 million or more in U.S. traded securities. If an institution consists of multiple individual funds, the individual holdings are aggregated.

This chapter only analyzes equity holdings because reporting of non-equity holdings is limited and does not include the majority of an institution's fixed income portfolio. Non-equity holdings are dropped from the sample by using the Issue Number of their CUSIP Number. An Issue Number is the 7th and 8th position of a CUSIP Number. Issue Numbers for equity securities contain only numeric values, whereas Issue Numbers for fixed income securities involve at least one alphabetic character.

Security data used are also from the FactSet LionShares Ownership Database. I use the CRSP (Center for Research in Security Prices) database when possible for securities data that is missing in the FactSet LionShares Ownership Database. I drop stocks from the sample during quarters in which they had a change in outstanding shares greater than 5 percent in magnitude because herding levels can be inflated when companies issue or repurchase stock. I also drop any stocks from the sample during quarters in which they had a price change greater than or equal to 40 percent in magnitude in order to reduce bad data and remove any stock-splits that were not adjusted for by FactSet.

Institutions in the data are only included in the analysis during quarters in which their equity portfolio value is greater than or equal to $25 million at the end of the quarter. The lower limit decreases the risk of poorly reported holdings. I also provide additional results that do not include institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter. I drop any institutions from the sample during quarters in which the change in their equity portfolio value is greater than 35 percent in magnitude to decrease the risk of poorly reported holdings.

Data include institutions' geographic locations and institution types. This chapter analyzes institutions that were located in the top 15 metropolitan areas ranked by institution count and were one of the top 5 institution types ranked by institution count. Table 2.1 shows the count of institutions by metropolitan area and institution type that are included in the analysis over the entire sample period. Roughly 40 percent of the institutions are located in the New York City metropolitan area, whereas the remaining 14 metropolitan areas individually make up less than 10 percent of the institutions in the sample. Roughly half of the 2,516 institutions are classified as Investment Advisers. Hedge Fund Companies account for almost 40 percent of institutions. The remaining institution types are Bank Management Divisions, Mutual Fund Managers, and Insurance Management Divisions. Hedge Fund Companies are largely concentrated in the New York City metropolitan area, whereas the other institution types are more evenly distributed between the metropolitan areas. Table B.5 in Appendix B.1 show similar counts for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter.

Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	Total
New York City	336	622	21	22	15	1,016
San Francisco	119	84	7	13	0	223
Boston	144	58	9	11	2	224
Chicago	119	37	17	2	5	180
Los Angeles	109	40	6	5	3	163
Philadelphia	87	17	15	4	1	124
Baltimore/Washington DC	72	11	9	8	0	100
London	43	30	7	8	7	95
Dallas/Fort Worth	29	34	5	2	1	71
Minneapolis	41	16	3	1	1	62
Toronto	26	5	5	15	3	54
Houston	39	8	5	0	0	52
Milwaukee	37	3	6	4	2	52
Atlanta	46	4	1	0	1	52
Richmond	41	5	2	0	0	48
Total	1,282	974	117	88	41	2,516

Table 2.1: Institution Count By Metropolitan Area And Institution Type

Table B.1 and Table B.2 in Appendix B.1 show a snapshot count of institutions by metropolitan area and institution type respectively over time from 2000-2010. The number of institutions in the sample increased from 810 at the end of 2000 to 1,457 at the end of 2010. Larger metropolitan areas observed a bigger increase in institution count due to large growths in Investment Advisers and Hedge Fund Companies. Table B.3 and Table B.4 in Appendix B.1 show similar counts for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter.

Table 2.2 shows a snapshot of the mean equity portfolio size by institution type over time from 2000-2010. The mean Hedge Fund Company portfolio is the smallest, whereas the mean Mutual Fund Manager portfolio is the largest. The weighted mean portfolio of all institutions included in the analysis increased by roughly $500 million during 2000-2005, but decreased slightly during 2005-2010. The total equity market cap held by all institutions included in the analysis is $5.1 trillion at the end of 2000, $5.6 trillion at the end of 2005, and $5.4 trillion at the end of 2010. Table B.6 in Appendix B.1 shows a snapshot of the mean equity portfolio size by institution type over time from 2000-2010 for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter. The weighted mean portfolio of all institutions included in the analysis increased by roughly $500 million during 2000-2005, but stayed level during 2005-2010. The total equity market cap held by all institutions included in the analysis is \$1.9 trillion at the end of 2000, \$2.4 trillion at the end of 2005, and \$2.4 trillion at the end of 2010. Comparing Table 2.2 and Table B.6 shows that the Mutual Fund Manager type is the most affected by excluding institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to \$50 billion at the end of the quarter.

Table B.7 in Appendix B.1 shows a snapshot of the mean number of equity holdings by institution type over time from 2000-2010. There is an increase in the mean number of stocks held by every institution type during 2000-2005, whereas the mean number of stocks held slightly decreased for each institution type during 2005-2010. Table B.8 in Appendix B.1 shows a snapshot of the mean number of equity holdings by institution type over time from 2000-2010 for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to \$50 billion at the end of the quarter. There is an increase in the mean number of stocks held by every institution type during 2000-2005, whereas the mean number of stocks held was relatively constant for each all institution types except Insurance Management Divisions during 2005-2010.

Table 2.3 shows a snapshot of the mean quarterly turnover rate for each institution type over time from 2000-2010. The quarterly turnover rate is calculated by dividing an institution's trading volume by their total equity portfolio value during the quarter. To calculate trading volume, I multiply the change in shares of each stock by the average of the stock's beginning and end

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	3,078	4,236	3,795
Hedge Fund Company	490	1,015	1,061
Bank Management Division	9,053	10,212	10,208
Mutual Fund Manager	38,444	42,902	41,273
Insurance Management Division	3,781	4,089	7,038
All	5,089	5,598	5,384

Table 2.2: Mean Market Cap ($ Millions) By Institution Type

of quarter price and sum across all stocks in an institution's portfolio. The total equity portfolio values used to calculate quarterly turnover rates are the average of the beginning and end of quarter equity portfolio values. Table 2.3 shows Hedge Fund Companies have a much higher turnover rate than the other institution types. The mean quarterly turnover rate for any institution type does not change much overtime, except for a decrease in mean quarterly turnover rates by Hedge Fund Companies during 2000-2005. This decrease is most likely due to the mean Hedge Fund Company size more than doubling during the same time period as reflected in Table 2.2. Table B.9 in Appendix B.1 shows similar results for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter.

Part of the analysis in this chapter examines herding between institu-

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	7.08	6.10	6.26
Hedge Fund Company	17.62	13.55	13.02
Bank Management Division	5.53	4.14	5.53
Mutual Fund Manager	6.26	6.45	5.27
Insurance Management Division	6.38	5.32	5.59
All	8.61	8.00	8.05

Table 2.3: Mean Quarterly Turnover Rate By Institution Type

tions when they make *major portfolio changes*. *Major portfolio changes* are defined as an institution buying a stock they did not own in the previous quarter or selling all of their holdings of a stock they did own in the previous quarter. Table B.10 in Appendix B.1 shows the mean quarterly turnover rate for each institution type over time only using *major portfolio changes* when calculating an institution's trading volume. Table 2.3 and Table B.10 show that the portion of trades considered *major portfolio changes* differ across institution type. The majority of Hedge Fund Companies' trades are considered *major portfolio changes*, while a small portion of Bank Management Divisions' trades are considered *major portfolio changes*. Table B.11 in Appendix B.1 shows similar results for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter.

2.3 Methodology

The herding measure used in this chapter is from Lakonishok et al. (1992) and is referred to as the "LSV Herding Statistic". The LSV Herding Statistic is the most widely used herding measure and allows a comparison between my results and other results. Advantages of using the LSV Herding Statistic also include robustness to poor data because it does not depend on stock prices or the total value of an institution's portfolio.

Define $n_{i,k,t}$ as the number of stock i's shares held by institution k at the end of quarter t. The change in stock i's shares held by institution k during quarter t is:

$$\Delta n_{i,k,t} = n_{i,k,t} - n_{i,k,t-1}. \tag{2.3.1}$$

Let $b_{i,k,t}$ and $s_{i,k,t}$ be dummy variables that indicate whether institution k was a net buyer or net seller of stock i's shares during quarter t:

$$b_{i,k,t} = \left\{ \begin{array}{ll} 1, & \text{if } \Delta n_{i,k,t} > 0 \\ 0, & \text{otherwise} \end{array} \right., \tag{2.3.2}$$

$$s_{i,k,t} = \left\{ \begin{array}{ll} 1, & \text{if } \Delta n_{i,k,t} < 0 \\ 0, & \text{otherwise} \end{array} \right.. \tag{2.3.3}$$

Let $B_{i,t}$ be the number of institutions that increase their holdings of stock i during quarter t and $S_{i,t}$ be the number of institutions that decrease their holdings of stock i during quarter t:

$$B_{i,t} = \sum_k b_{i,k,t}, \tag{2.3.4}$$

$$S_{i,t} = \sum_k s_{i,k,t}. \tag{2.3.5}$$

$$\tag{2.3.6}$$

Define the LSV Herding Statistic for stock i during quarter t as:

$$LSV_{i,t} = \big[|\frac{B_{i,t}}{B_{i,t} + S_{i,t}} - p_t| - AF_{i,t}\big] \times 100\%, \tag{2.3.7}$$

where p_t is the expected proportion of all institutions trading stock i during quarter t that are buyers and $AF_{i,t}$ is an adjustment factor. Each quarter, p_t is approximated by $\sum_i B_{i,t}/(\sum_i B_{i,t} + \sum_i S_{i,t})$. An adjustment factor is needed because the expected value of $|\frac{B_{i,t}}{B_{i,t}+S_{i,t}} - p_t|$ is greater than zero. Therefore, $AF_{i,t}$ is the expected value of $|\frac{B_{i,t}}{B_{i,t}+S_{i,t}} - p_t|$ under the null hypothesis of no herding:

$$AF_{i,t} = \mathbb{E}\big[|\frac{B}{B + S} - p_t|\big], \tag{2.3.8}$$

where B is a random variable that follows a binomial distribution with probability p_t of success and $N_{i,t}$ trials, $N_{i,t}$ is the number of institutions changing their number of stock i's shares held during quarter t, and $S = N_{i,t} - B$. It is appropriate to examine herding within stocks that several institutions are trading rather than stocks with only a few active trades, therefore I only calculate (2.3.7) for stock-quarters with at least five active trades.

Herding cannot exist between the entire investing population when the total outstanding shares of stocks are fixed because there must be a buyer for every seller and vice versa. The data sample used is large and is considered a good representation of the entire investing population, therefore the LSV Herding Statistic is calculated for subgroups of institutions representing herding networks. The first way networks are formed is by grouping institutions by institution type, the second way is by grouping institutions by metropolitan area, and the third way is by grouping institutions by institution type and metropolitan area. For brevity, the following naming convention is used:

1. "*Type* networks" = 5 subgroups of institutions formed by institution type,
2. "*Metro* networks" = 15 subgroups of institutions formed by metropolitan area,
3. "*TypeMetro* networks" = 75 subgroups of institutions formed by institution type and metropolitan area.

The 5 institution types chosen are the top 5 institution types ranked by count. The 15 metropolitan areas chosen are the top 15 metropolitan areas ranked by count. In all three network formations, only institutions that are in the top 5 institution types and top 15 metropolitan areas are used in the analysis. Other institutions are dropped from the sample.

The mean LSV Herding Statistic for a subgroup of institutions is calculated by averaging the LSV Herding Statistic over all stock-quarters using only trades by that subgroup.

2.3.1 LSV Herding Statistic Interpretation

Consider a hypothetical scenario where on average 60% of all trades are buys and 40% of all trades are sells by a subgroup of institutions. A mean LSV Herding Statistic of 5.00% can be interpreted as 65% of institutions are changing their holdings of an average stock in one direction and 35% in the opposite direction.

Fund managers within an institution communicate and often use the same research when making investment decisions. Thus, fund managers from the same institution buy and sell the same stocks on average more than two unrelated funds. Therefore, mean LSV Herding Statistics are lower when using aggregated institutional holdings than when using fund level data. Many empirical herding papers use fund level data, thus a conversion factor should be used in order to compare the results in this chapter with results that use fund level data. Wermers (1999) compares the mean LSV Herding Statistic calculated using individual mutual funds and the mean LSV Herding Statistic calculated by aggregating holdings of the same individual funds within their fund family. Wermers (1999) finds aggregating individual fund holdings decreases herding statistics: "Roughly two percent more fund families, on average, are on the same side of trading than expected, while approximately three to four percent more individual funds ... are on the same side than expected." Mean LSV Herding Statistics calculated using fund level data are between 1.5 to 2.0 times larger than mean LSV Herding Statistics calculated using aggregated holdings of the same funds. A conservative conversion factor of 1.5 is used to compare the results in this chapter with other results that use fund level data.

2.4 Results

2.4.1 Main Results

Table 2.4 presents the main results in this chapter. The first column displays the weighted mean LSV Herding Statistic for each network formation methodology. The weighted mean LSV Herding Statistic is determined by averaging the mean LSV Herding Statistic for each network within a network formation methodology, weighting by number of stock-quarters. The second column displays the weighted mean LSV Herding Statistic for each network formation methodology using only *major portfolio changes*.

Network Formation Methodology	Weighted Mean LSV Herding Statistic	Weighted Mean LSV Herding Statistic (*Major Portfolio Changes*)
5 *Type* Networks	1.668**	3.887**
15 *Metro* Networks	0.944**	3.056**
75 *TypeMetro* Networks	0.944**	3.705**

Table 2.4: Weighted Mean LSV Herding Statistic By Network Formation Methodology: † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

The 5 *Type* networks' mean LSV Herding Statistic is 1.668% which is almost twice as much as the 15 *Metro* networks' mean LSV Herding Statistic of 0.944%. Hong et al. (2005) show that mutual fund managers spread information to one another by word of mouth and are likely to herd with other mutual funds in the same city. The results suggest networks between institutions of the same type are stronger than networks between institutions in the same metropolitan area. Furthermore, the 75 *TypeMetro* networks' mean LSV Herding Statistic of 0.944% suggests the networks between institutions of the same type exist across metropolitan areas because truncating networks by metropolitan area substantially decreases the level of herding.

The results suggest that institutional herding is more likely due to similar risk appetites or similar investment strategies rather than information cascades because herding is stronger between networks formed by institution type rather than by metropolitan area. However, reputation herding is also a possibility because it can exist in networks formed by institution type or metropolitan area.

The second column in Table 2.4 shows higher levels of herding for all three network formations when calculating the LSV Herding Statistic only using *major portfolio changes*. The fact that herding is stronger when institutions make *major portfolio changes* suggests institutions herd based on reputation concerns. It is reasonable to conclude that an institution's reputation is affected much more by liquidating a 1 percent holding in a given security than changing a holding of a security from 1 to 2 percent. Whereas, fund returns are a linear function with respect to the amount of a security an institution holds. Again, networks formed by institution type herd more than networks formed by metropolitan area when making *major portfolio changes*.

Lakonishok et al. (1992) describe their overall mean LSV Herding Statistic of 2.7% as relatively little herding, but their mean LSV Herding Statistic of 6.1% conditioning on the smallest quintile stocks as evidence of herding. Using a conversion factor of 1.5, the 5 *Type* networks' mean LSV Herding Statistic is $1.668\% \times 1.5 = 2.502\%$. Therefore, the magnitude of the herding detected in my data when considering all types of trades is not considerably large. Only considering *major portfolio changes*, the mean LSV Herding Statistic for the 5 *Type* networks formed is $3.887\% \times 1.5 = 5.831\%$ which is considered economically significant.

2.4.2 Detailed Results by Network

Appendix B.2 contains details of the LSV Herding Statistic by network for each network formation methodology. In addition to mean LSV Herding Statistics, a signed herding measure is also presented. The mean "Buy" LSV Herding Statistic is calculated by averaging the LSV Herding Statistic over stock-quarters where $\frac{B_{i,t}}{B_{i,t}+S_{i,t}} > p_t$ and the mean "Sell" LSV Herding Statistic is calculated by averaging the LSV Herding Statistic over stock-quarters where $\frac{B_{i,t}}{B_{i,t}+S_{i,t}} < p_t$. The mean LSV Herding Statistic shown for "All" is calculated by averaging mean LSV Herding Statistics for each network, weighting by number of stock-quarters.

Table B.12 in Appendix B.2 shows mean LSV Herding Statistics for the 5 *Type* networks. Table B.12 shows Hedge Fund Companies herd more than any other institution type when considering all portfolio changes, but herd the least when making *major portfolio changes*. Therefore, herding by hedge funds is more likely due to similar risk appetite or investment strategies rather than reputational considerations. Table B.13 in Appendix B.2 shows similar results for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter. Hedge funds use performance fees more than other institutions, therefore the results in this chapter support the conclusion in Wilson (2012) that performance fees deter reputation herding.

Table B.14, Table B.15, and Table B.16 in Appendix B.2 show mean LSV Herding Statistics for the 15 *Metro* networks. The differences in herding levels between networks formed by metropolitan area are not as great as by institution type. Institutions in the New York City metropolitan area herd more together than any other metropolitan area when considering all types of portfolio changes, reflecting the number of hedge funds in the metropolitan area. As expected, the herding level in the New York City metropolitan area does not increase as much as most metropolitan areas when only considering *major portfolio changes* because New York City metropolitan area consists mostly of Hedge Funds. Table B.17, Table B.18, and Table B.19 in Appendix B.2 show similar results for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter.

Table B.20, Table B.21, Table B.22, and Table B.23 in Appendix B.2 show mean LSV Herding Statistics for the 75 *TypeMetro* networks using all portfolio changes and Table B.28, Table B.29, Table B.30, and Table B.31 show mean LSV Herding Statistics for the 75 *TypeMetro* networks using only *major portfolio changes*. The New York City metropolitan area and Hedge Fund

Companies still have the highest level of herding when considering all portfolio changes and some of the lowest levels of herding when only considering *major portfolio changes*. Similar results are shown in Table B.24, Table B.25, Table B.26, Table B.27, Table B.32, Table B.33, Table B.34, and Table B.35 for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter.

The results in Section 2.4.1, showing institutional investors' stronger tendency to herd when making *major portfolio changes*, is not due to a few network outliers. The tables in Appendix B.2 show that every network in every network formation methodology has a stronger tendency to herd when making *major portfolio changes*. In addition, the tables in Appendix B.2 show institutional investors herd more when buying stocks than when selling stocks on average.

2.4.3 Detailed Results by Market Capitalization and VIX Quintiles

Appendix B.3 contains details of the LSV Herding Statistic by market capitalization and VIX quintiles for each network formation methodology. Cut-off points for market capitalization quintiles are formed each quarter by grouping every stock in the NYSE, NASDAQ, and AMEX stock exchanges from the CRSP database into market capitalization quintiles. VIX is the Chicago Board Options Exchange Market Volatility Index that measures the implied volatility of S&P 500 index options over the following 30 day period.

This chapter classifies each quarter in the sample time period by VIX quintiles based on the average daily VIX value for the quarter. Although previous empirical herding papers review market capitalization, this chapter is the first to examine the relationship between herding and market volatility.

Table B.36, Table B.40, and Table B.44 in Appendix B.3 show the weighted mean LSV Herding Statistic by market capitalization and VIX quintiles for the 5 *Type*, 15 *Metro*, and 75 *TypeMetro* networks respectively using all portfolio changes. The smallest market capitalization quintile exhibits the most herding all network formations. The herding difference between VIX quintiles is not large for any network formation using all portfolio changes. Table B.37, Table B.41, and Table B.45 in Appendix B.3 show the weighted mean LSV Herding Statistic by market capitalization and VIX quintiles for the 5 *Type*, 15 *Metro*, and 75 *TypeMetro* networks respectively using all portfolio changes for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter. Excluding institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter decreases herding in small cap stocks. Thus, the herding in small cap stocks is done mostly by larger institutions.

Table B.38, Table B.42, and Table B.46 in Appendix B.3 show the weighted mean LSV Herding Statistic by market capitalization and VIX quintiles for the 5 *Type*, 15 *Metro*, and 75 *TypeMetro* networks respectively using only *major portfolio changes*. In all network formation methodologies, herding is monotonically decreasing with respect to market capitalization quintile. Using a conversion factor of 1.5, the smallest market capitalization quintile has a weighted mean LSV Herding Statistic of $13.334\% \times 1.5 = 20.001\%$, $11.093\% \times 1.5 = 16.640\%$, and $10.594\% \times 1.5 = 15.891\%$ for the 5 *Type*, 15 *Metro*, and 75 *TypeMetro* networks respectively. Therefore, the herding in small cap stocks using *major portfolio changes* is economically significant for all three network formation methodologies. Again, the herding difference between VIX quintiles is not large for any network formation using all portfolio changes. Similar results are shown in Table B.39, Table B.43, and Table B.47 in Appendix B.3 for the data sample that excludes institutions in the analysis during quarters in which their equity portfolio value is greater than or equal to $50 billion at the end of the quarter.

The herding results in this chapter for the smallest market capitalization quintile are consistent with Lakonishok et al. (1992), Wermers (1999), and other previous empirical studies. Lakonishok et al. (1992) found their herding results in small market cap stocks disappeared when conditioning on stocks that had very little change in outstanding shares. This chapter shows the stronger herding in small market cap stocks still persists when only considering stocks during quarters with trivial changes in outstanding shares. This chapter adds to the existing literature by showing the difference in herding between small cap stocks and large cap stocks is increased when only considering *major portfolio changes*.

Herding within small cap stocks is typically attributed to information cascades because there is less information about these stocks readily available to the investing public than there is in large cap stocks. However the increase in herding is the largest for small cap stocks when using only *major portfolio changes*. This suggests herding in small cap stocks is due to reputational herding.

This chapter is the first to examine the relationship between market volatility and institutional herding. Information cascades may occur more frequently during volatile quarters than quarters without much uncertainty. Herding and volatility may also be related by a feedback loop due to institutions using the same investment strategy associated with volatility and hence causing more volatility. The results in this chapter show no relationship between volatility and institutional herding when analyzing quarterly holdings. It is possible that institutional herding and market volatility are correlated, but the relationship cannot be seen without using higher frequency data.

2.5 Conclusion

Using quarterly holding data from 2000-2010, I found stronger herding networks between similar types of institutions compared to institutions in the same metropolitan area. Furthermore, the herding network between similar types of institutions exists across metropolitan areas. Results showed institutions herd more when making major portfolio changes than when making minor portfolio changes. The difference in herding between the two types of portfolio changes is greatest for small cap stocks which exhibit the highest levels of herding under both types of portfolio changes. The relationship between market volatility and herding by institutions were also examined and found not to have a strong correlation using quarterly holdings data.

Chapter 3

Production Tax Credits and Wind Energy Investments: A Real Options Approach with Regime Shifts and Jumps

3.1 Introduction

Wind energy is a crucial component of the world's energy solution as our natural resources become increasingly depleted and emerging economies become progressively energy hungry. The European Union estimates that by 2020, wind energy could satisfy 10 to 15 percent of the total EU electricity demand (see Blanco (2009)). In 2008, the United States relied on coal and natural gas for 70 percent of their electricity production[1]. Conversely, hydroelectricity encompassed roughly 6 percent of the U.S. electricity production, and other renewable sources, such as wind and solar, made up only 3 percent of the total electricity supply in 2008. In order for the U.S. to succeed in encouraging renewable energy investments, they need to determine the dependency of government policies for renewable energy investments and understand the factors that influence investment decisions made by potential renewable energy

[1] Electricity generation by energy source data can be found at the Department of Energy's Energy Information Administration website: http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html.

plants. This chapter provides a real options approach to evaluate Production Tax Credits (PTCs), cost reductions, and efficiency improvements regarding wind energy investments.

As part of the American Recovery and Reinvestment Act of 2009, the United States federal government extended PTCs that provide a 2.2 cent per kilowatt hour (kWh) subsidy for plants producing renewable wind energy during their first ten years of operation. Vestas Wind Systems, a firm specializing in wind energy production, claims PTCs play a large role in their $1 billion plan to build six energy factories in Colorado and a research center in Houston (see Glader (2009)). Understanding the necessity of PTCs in Vestas Wind Systems' investment decision, and similar investment decisions, is necessary to competently encourage renewable energy investments.

Welch and Venkateswaran (2009) analyze the dependence of wind energy investments on PTCs and suggest that PTCs can be lowered to 0.1 cent per kWh at current cost levels and PTCs are no longer needed with reasonable cost and/or technology improvements. Welch and Venkateswaran (2009) use the naive NPV rule that indicates to invest in a project if the present value of the future profit stream exceeds the investment cost. The NPV rule assumes that either the investment is reversible, or the investment decision must be made in the current period if it is irreversible (see Dixit and Pindyck (1994)). This methodology does not include the interaction between uncertainty, the irreversibility of the investment, and the possibility of deferring the project (see Bellamy and Sahut (2007)). In the case of wind energy investment, the initial investment can be more than 80 percent of the plant's costs over its lifespan (see Blanco (2009)). Therefore, the irreversibility characteristic of the investment opportunity plays a large role in the investment decision and the option to defer the investment decision is a critical factor to model. Although an investment's NPV may be positive, the benefit of waiting for new information can exceed foregone cash flows. According to Dixit and Pindyck (1994), the benefit of delaying investment to gather additional information is often large and using the NPV rule can result in drastic calculation errors.

This chapter is the first to specifically address the differences between a NPV rule model and a real options model when analyzing wind energy investments and PTCs. The real options model developed in this chapter builds on the framework discussed in Dixit and Pindyck (1994), and uses mathematical tools found in Boyarchenko and Levedorskiĭ (2007) to solve the investment problem.

Gollier et al. (2005) use real options to evaluate investments in nuclear power assuming the price of electricity follows a geometric Brownian motion. The basic geometric Brownian motion assumption describes normal idiosyncratic risk well, but some recent papers in real options use regime shifts and jumps in addition to geometric Brownian motion to incorporate broader risks. Hackbarth et al. (2006) and Boyarchenko (2009) consider regime shifts and jumps in real options models in the area of credit risk. Guo et al. (2005) consider regime shifts in the case of capital investments. Bellamy and Sahut (2007) incorporate the possibility of a one-time sudden drop in future wind energy cash flows caused by the discovery of new oil reserves or alternative energy sources in their real options model that assumes electricity prices follow geometric Brownian motion. This chapter improves upon Bellamy and Sahut (2007) by being the first to analyze wind energy investments using a model regime shifts and jumps.

In contrast to Welch and Venkateswaran (2009), who argue PTCs can be lowered to \$0.01/kWh, my results show that wind energy plants will most likely not invest even at current PTCs levels of \$0.022/kWh. Although the net present value of the investment is positive using my baseline assumptions, potential wind energy plants will wait to resolve uncertainty. The basic model in this chapter predicts a PTCs level of \$0.0235/kWh is needed to induce immediate investment in wind energy.

In addition to a basic model using geometric Brownian motion, this chapter analyzes two scenarios using a stochastic price process with regime shifts and jumps. The first scenario assumes the current electricity market is regulated, but there is a possibility of it becoming deregulated in the future. The second scenario assumes the GBM drift of the electricity price shifts back and forth between two regimes due to booms and busts of oil prices. In both scenarios, the current level of PTCs is not large enough for immediate investment in wind energy.

Welch and Venkateswaran (2009) state that PTCs may be removed with reasonable cost and efficiency improvements, but my results using a real options model provide different results. I analyze multiple cost and efficiency scenarios under the different models. In all models, the improvements in cost and efficiency are greater than what would be deemed reasonable.

The rest of the chapter is organized as follows. The basic model without regime shifts and jumps or government policy is described and solved in closed form in Section 3.2. Section 3.2.3 incorporates PTCs in the basic model. Section 3.2.4 gives a background on regime shifts and jumps and develops a model using them to analyze wind energy investments. Section 3.3 discusses calibration of the parameters. Section 3.4 presents results and Section 3.5 concludes the chapter.

3.2 Model

3.2.1 Wind Energy Output

All costs and revenues are proportional to the size of a wind energy plant, therefore this chapter looks at the investment decision of one kWh capacity in wind energy. Due to engineering limitations and the inability to control nature, wind energy plants do not produce at their full capacity (see Welch and Venkateswaran (2009)). Let the utilization rate, UR, be the percentage of the plant's capacity that plants are able to produce. Let Hrs be the number of hours in a time period. The output level, Q, of one unit of energy capacity is:

$$Q = UR \cdot Hrs \quad kWh. \tag{3.2.1}$$

Currently, there is not a good storage device for energy produced by wind turbines (see Blanco (2009)). In my model, the probability that the price of electricity falls below the wind energy plant's low operating costs is very small and the wind energy plant is able to sell all electricity produced at the market price, therefore it is always profitable for the wind energy plant to produce as much electricity as possible.

3.2.2 Basic Model

3.2.2.1 Operating Cash Flows and Profit Function without PTCs

Wind energy plants are price takers because they produce a small portion of the United States' electricity. The wind energy plant's selling price of electricity is exogenous and modeled by $p_t = Ge^{X_t}$, where G is a positive constant and X is a Brownian motion under the equivalent martingale measure for no arbitrage pricing:

$$X_t = x + \int_0^t \mu dt + \int_0^t \sigma dW_t, \tag{3.2.2}$$

where x is the spot value of X, W is the standard Wiener process, and $\mu \in \mathbb{R}$ and $\sigma > 0$. The equivalent martingale measure is unique.

Geometric Brownian motion (GBM) is a better assumption than standard Brownian motion because it is bounded below by zero and the drift and volatility of the process is proportional to the current price level. A consequence of using a random walk process without mean reversion is the price can diverge over time and firms can earn infinite profits. Realistically, new firms would enter the market when a price increase occurs and the shift in the supply curve would lead to a decrease in price if demand curves are downward sloping. Therefore, some critics argue that GBM with mean reversion is a more plausible assumption than GBM.

Hassett and Metcalf (1995) compare GBM and mean reversion process models and find cumulative investment is generally the same under both assumptions. Prices that follow GBM have a larger long-run variance than prices that follow mean reversion. The inverse relationship between uncertainty and investment implies investors are more willing to invest under a mean reversion process assumption. On the other hand, the higher volatility of GBM implies higher price levels are achievable. This effect will cause investors to be more willing to invest under a GBM assumption. These two opposing effects are shown to offset each other so that expected cumulative investment over time is roughly the same under either price process assumption. Therefore, this chapter assumes GBM because it is analytically less complex.

Let AVE be the average variable expenses measured in \$/kWh. Let $O\&M$ be the operating and maintenance cost measured in \$:

$$O\&M = AVE \cdot Q. \tag{3.2.3}$$

Wind energy plants typically apply their capital depreciation for tax purposes over a 5 year schedule described in Welch and Venkateswaran (2009). This chapter makes the simplifying assumption that capital depreciation is spread out over the entire lifespan of the plant for tax purposes. The plant faces a tax rate τ. Let δ be the capital depreciation the plant is able to subtract from their taxable income each period. The tax the plant pays each period is:

$$tax = (Q \cdot p_t - O\&M - \delta)\tau \quad \forall t. \tag{3.2.4}$$

Using the substitution $p_t = Ge^{X_t}$, the profit function for the wind energy plant can be written as:

$$\Pi(p_t) = Q \cdot Ge^{X_t}(1-\tau) - O\&M(1-\tau) + \delta \cdot \tau \quad \forall t. \tag{3.2.5}$$

For ease of notation, let $\alpha = Q \cdot G(1-\tau)$ and $\gamma = O\&M(1-\tau) - \delta \cdot \tau$. (3.2.5) can be rewritten as:

$$\Pi(p_t) = \alpha e^{X_t} - \gamma \quad \forall t. \tag{3.2.6}$$

3.2.2.2 Calculation of Investment Threshold and Investment Option Value without PTCs

The potential wind energy plant will make the decision to invest when the price of electricity becomes sufficiently high. As noted by Dixit and Pindyck (1994), the price of electricity that triggers investment will be higher than the price that makes the NPV positive. This reflects the irreversibility of the investment decision and the benefit of waiting for new information. The plant will invest when X reaches, or crosses for the first time, the investment threshold denoted by h. The stopping time, τ_h, is a random variable that denotes the first time X reaches or crosses h:

$$\tau_h = \inf\{t \geq 0; X_t \geq h\}. \tag{3.2.7}$$

The wind energy plant faces a one-time investment cost I and discounts future cash flows with interest rate r. Using the normalized investment cost rI, the value of the option to invest in wind energy is:

$$V(x;h) = \mathbb{E}^x[\int_{\tau_h}^{\infty} e^{-rt}(\alpha e^{X_t} - \gamma - rI)dt]. \tag{3.2.8}$$

The expectation in (3.2.8) is conditional on the spot price x of the Brownian motion X. The lower bound of the integral shows the plant will incur the investment cost and start receiving profit flows at time τ_h.

The no-bubble condition for the wind energy plant's profit flow is:

$$\mathbb{E}^x[\int_0^{\infty} e^{-rt}\Pi(p_t)dt] < \infty. \tag{3.2.9}$$

Let $\Psi(z) = \mu z + \sigma^2 \frac{z^2}{2}$ be the Lévy exponent of Brownian motion X. The no-bubble condition is satisfied by:

$$r - \Psi(1) > 0. \tag{3.2.10}$$

This chapter uses the Wiener-Hopf factorization method described in Boyarchenko and Levedorskiǐ (2007) to calculate (3.2.8). Let the supremum and infimum processes of X be defined by $\overline{X}_t = sup_{0\le s\le t} X_s$ and $\underline{X}_t = inf_{0\le s\le t} X_s$ respectively. The normalized expected present value (EPV) operators $\mathcal{E}^{\pm}$ for payoff stream $g(X_t)$ are defined by:

$$\mathcal{E}^{+} g(x) = r\mathbb{E}[\int_0^{\infty} e^{-rt} g(x + \overline{X}_t)dt], \tag{3.2.11}$$

$$\mathcal{E}^{-} g(x) = r\mathbb{E}[\int_0^{\infty} e^{-rt} g(x + \underline{X}_t)dt], \tag{3.2.12}$$

$$\mathcal{E}g(x) = r\mathbb{E}[\int_0^{\infty} e^{-rt} g(X_t)dt], \tag{3.2.13}$$

$$\mathcal{E}g(x) = \mathcal{E}^{-}\mathcal{E}^{+}g(x) = \mathcal{E}^{+}\mathcal{E}^{-}g(x). \tag{3.2.14}$$

Let $\beta^{\pm}$ be the positive and negative roots of the characteristic equation:

$$r - \Psi(\beta) = 0. \tag{3.2.15}$$

The EPV-operators can then be written as:

$$\mathcal{E}^{+}g(x) = \int_0^{+\infty} \beta^{+} e^{-\beta^{+}y} g(x+y)dy, \tag{3.2.16}$$

$$\mathcal{E}^{-}g(x) = \int_{-\infty}^{0} -\beta^{-} e^{-\beta^{-}y} g(x+y)dy. \tag{3.2.17}$$

The value of the option to invest in wind energy shown in (3.2.8) can be rewritten as:

$$\begin{aligned} V(x;h) &= \mathbb{E}^{x}[\int_0^{\infty} e^{-rt}(\alpha e^{X_t} - \gamma - rI)dt] + W(x;h) \\ &= r^{-1}\mathcal{E}g(x) + W(x;h), \end{aligned} \tag{3.2.18}$$

where $g(X_t) = \alpha e^{X_t} - \gamma - rI$ and:

$$W(x;h) = \mathbb{E}^{x}[\int_0^{\tau_h} e^{-rt}(-g(X_t))dt]. \tag{3.2.19}$$

(3.2.19) is an exit problem, where the plant exits when X reaches or crosses h from below for the first time. Using the infinitesimal generator L, Appendix C.1.1 shows (3.2.19) can be rewritten as,

$$(r - L)W(x;h) = -g(x), \quad x < h. \tag{3.2.20}$$

The firm's value is zero after exiting,

$$W(x;h) = 0, \quad x \geq h. \tag{3.2.21}$$

Boyarchenko and Levedorskiĭ (2007) prove that $W(x,h)$ can be written in terms of EPV-operators:

$$W(x;h) = r^{-1}\mathcal{E}^{+}\mathbf{1}_{(-\infty,h)}\mathcal{E}^{-}(-g)(x). \tag{3.2.22}$$

Using (3.2.14) and substituting (3.2.22) into (3.2.18), the value of the option to invest in wind energy is:

$$\begin{aligned} V(x;h) &= r^{-1}\mathcal{E}^{+}\mathcal{E}^{-}g(x) - r^{-1}\mathcal{E}^{+}\mathbf{1}_{(-\infty,h)}\mathcal{E}^{-}g(x) \\ &= r^{-1}\mathcal{E}^{+}(\mathbf{1}_{(-\infty,h)} + \mathbf{1}_{[h,+\infty)})\mathcal{E}^{-}g(x) - r^{-1}\mathcal{E}^{+}\mathbf{1}_{(-\infty,h)}\mathcal{E}^{-}g(x) \\ &= r^{-1}\mathcal{E}^{+}\mathbf{1}_{[h,+\infty)}\mathcal{E}^{-}g(x). \end{aligned} \tag{3.2.23}$$

Using the optimal investment threshold h^{*}, the value of the option to invest in wind energy is:

$$V(x) = r^{-1}\mathcal{E}^{+}\mathbf{1}_{[h^{*},+\infty)}\mathcal{E}^{-}g(x). \tag{3.2.24}$$

This chapter uses the general formulas for $\kappa^{\pm}(z)$ and a property found in Boyarchenko and Levedorskiĭ (2007):

$$\kappa^{\pm}(z) = \frac{\beta^{\pm}}{\beta^{\pm} - z}, \tag{3.2.25}$$

$$\frac{r}{r - \Psi(z)} = \kappa^{+}(z)\kappa^{-}(z). \tag{3.2.26}$$

Two important properties of the EPV-operators when is $g(X_t)$ is in the form $g(X_t) = Ge^{zX_t}$ are:

$$\mathcal{E}^{\pm}g(x) = \kappa^{\pm}(z)g(x), \tag{3.2.27}$$

$$\mathcal{E}g(x) = \frac{r}{r - \Psi(z)} g(x). \tag{3.2.28}$$

To calculate h^*, find where $\mathcal{E}^- g(h) = 0$. h^* solves:

$$\mathcal{E}^-(\alpha e^h - \gamma - rI) = 0. \tag{3.2.29}$$

Using (3.2.27), h^* solves:

$$\alpha\kappa^-(1)e^h - \gamma - rI = 0. \tag{3.2.30}$$

$$\Rightarrow h^* = \ln[\frac{\gamma + rI}{\alpha\kappa^-(1)}], \tag{3.2.31}$$

where the condition $\gamma + rI > 0$ is needed. Using (3.2.16), (3.2.24) can be written for any $x < h^*$ as:

$$V(x) = r^{-1}(\beta^+) \int_{h^*-x}^{+\infty} e^{-\beta^+ y}[\alpha\kappa^-(1)e^{x+y} - \gamma - rI]dy. \tag{3.2.32}$$

Calculating the integral and using properties (3.2.25) and (3.2.26), (3.2.32) can be calculated as:

$$V(x) = \frac{\alpha}{r - \Psi(1)} e^{h^*(1-\beta^+)+x\beta^+} - \frac{\gamma + rI}{r} e^{(x-h^*)\beta^+}. \tag{3.2.33}$$

For any $x \geq h^*$, the plant invests immediately. Using properties (3.2.13) and (3.2.28), (3.2.24) can be calculated as:

$$V(x) = \frac{\alpha}{r - \Psi(1)} e^x - \frac{\gamma}{r} - I. \tag{3.2.34}$$

3.2.3 Basic Model with Production Tax Credits

3.2.3.1 Operation Cash Flows and Profit Function with PTCs

A policy to encourage investment in renewable energy is to offer Production Tax Credits (PTCs), denoted in the model as PTC. PTCs are a price subsidy measured in \$/kWh and are not taxable. Under the American Recovery and Reinvestment Act of 2009, PTCs are currently provided for the first 10 years of operation, but I model PTCs being provided for the lifespan of the plant. An adjustment is made during calibration of the model to reflect the difference.

The profit function for the wind energy plant with PTCs is written as:

$$\Pi(p_t) = Q \cdot Ge^{X_t}(1-\tau) - O\&M(1-\tau) + \delta \cdot \tau + PTC \cdot Q \quad \forall t. \tag{3.2.35}$$

Using previous notation, $\alpha = Q \cdot G(1-\tau)$ and $\gamma = O\&M(1-\tau) - \delta \cdot \tau$, the profit function shown in (3.2.35) can be rewritten as:

$$\Pi(p_t) = \alpha e^{X_t} - \gamma + PTC \cdot Q \quad \forall t. \tag{3.2.36}$$

3.2.3.2 Calculation of Investment Threshold and Investment Option Value with PTCs

With the addition of PTCs, the value of the option to invest in wind energy can be written as:

$$V(x;h) = \mathbb{E}^x[\int_{\tau_h}^{\infty} e^{-rt}(\alpha e^{X_t} - \gamma + PTC \cdot Q - rI)dt], \tag{3.2.37}$$

where τ_h is the stopping time described in Section 3.2.2.2.

The same no-bubble condition used before is imposed on the wind energy plant's profit flow:

$$r - \Psi(1) > 0. \tag{3.2.38}$$

The value function can again be written in the form of:

$$V(x;h) = r^{-1}\mathcal{E}^{+}\mathbf{1}_{[h,+\infty)}\mathcal{E}^{-}g(x), \tag{3.2.39}$$

where $g(X_t) = \alpha e^{X_t} - \gamma + PTC \cdot Q - rI$. Using the optimal investment threshold h^*, the value function is written as:

$$V(x) = r^{-1}\mathcal{E}^{+}\mathbf{1}_{[h^*,+\infty)}\mathcal{E}^{-}g(x). \tag{3.2.40}$$

To calculate h^*, find where $\mathcal{E}^{-}g(h) = 0$. h^* solves:

$$\mathcal{E}^{-}(\alpha e^{h} - \gamma + PTC \cdot Q - rI) = 0. \tag{3.2.41}$$

Using (3.2.27), h^* solves:

$$\alpha\kappa^{-}(1)e^{h} - \gamma + PTC \cdot Q - rI = 0. \tag{3.2.42}$$

$$\Rightarrow h^* = \ln[\frac{\gamma - PTC \cdot Q + rI}{\alpha\kappa^{-}(1)}], \tag{3.2.43}$$

where the condition $\gamma - PTC \cdot Q + rI > 0$ is needed.

Using (3.2.16), (3.2.40) can be written for any $x < h^*$ as:

$$V(x) = r^{-1}(\beta^{+})\int_{h*-x}^{+\infty} e^{-\beta^{+}y}[\alpha\kappa^{-}(1)e^{x+y} - \gamma + PTC \cdot Q - rI]dy. \tag{3.2.44}$$

Calculating the integral and using the properties (3.2.25) and (3.2.26), (3.2.44) can be calculated as:

$$V(x) = \frac{\alpha}{r - \Psi(1)}e^{h^*(1-\beta^{+})+x\beta^{+}} - \frac{\gamma - PTC \cdot Q + rI}{r}e^{(x-h^*)\beta^{+}}. \tag{3.2.45}$$

For any $x \geq h^*$ the plant invests immediately. Using properties (3.2.13) and (3.2.28), (3.2.40) can be calculated as:

$$V(x) = \frac{\alpha}{r - \Psi(1)} e^x - \frac{\gamma}{r} + \frac{PTC \cdot Q}{r} - I. \tag{3.2.46}$$

3.2.4 Model with Regime Shifts and Jumps

3.2.4.1 Regime Shifts and Jumps Background

There is an extensive literature showing oil prices follow a stochastic process with regime shifts and jumps (see Hamilton (2009) literature review). Hamilton (2009) shows a strong interaction between high oil prices and macroeconomic booms and recessions. Although oil is a small part of electricity production, oil prices have a strong correlation with electricity prices because other fossil fuels compete with both forms of energy[2]. Investments for renewable clean energy rise and fall with the price of oil (see Ball (2009)). James Dehlsen started Clipper Windpower in 1980 when oil prices were rising, but by 1985 oil prices dropped resulting in the loss of private financing for wind energy (see Ball (2009)). More recent renewable energy projects are also making their decisions based on the price of oil. Oilman T. Boone Pickens made plans for a $10 billion wind farm in Texas when the price of crude oil was high, but delayed investment in 2009 due to low oil prices hovering around $50 per barrel (see Glader (2009)). The unpredictability of OPEC furthers the

[2]Using average annual prices from 1973-2010, a correlation value of 0.753 using nominal prices and a correlation value of 0.450 using detrended prices between oil and electricity is found. Data are from the Department of Energy's Energy Information Administration website: http://www.eia.doe.gov.

uncertainty of oil, and therefore electricity prices. Ball (2009) states that fossil fuels follow boom-and-bust periods that interrupt the development and adoption of alternative energy. These boom-and-bust periods are appropriately modeled by regime shifts and jumps.

Government policies affecting the price path of electricity is also largely correlated with oil prices. According to IHS Global Insight, hybrid cars currently represent only 2 percent of the light-vehicle market (see Vranica (2009)). In order to decrease the United States' dependence on oil, the Obama administration recently accelerated the mandate for auto makers to increase the fuel economy of cars sold in the U.S. to 35.5 miles per gallon by 2016 (see Power and Conkey (2009)). This is the largest government-mandated transformation of vehicles since the late 1970s and early 1980s (see Power and Conkey (2009)). President Obama and other politicians have also proposed to cap the emissions of greenhouse gases, and force polluters to purchase emission permits that can be traded on the free market (see Weisman and Hughes (2009)). In addition, the Environmental Protection Agency is allowed to use the Clean Air Act to increase fuel-efficiency standards for automobiles (see Weisman and Hughes (2009)). These policies could have substantial effects on the price of electricity that would not be captured through geometric Brownian motion without regime shifts and jumps.

Deregulation of electricity markets is also aptly modeled with regime shifts and jumps. The three distinct electricity market sectors are generation, transmission, and distribution (see Fiorenzani (2006)). The transmission and distribution markets are usually regulated by government because they are natural monopolies and regulation ensures generating plants can compete fairly by having equal access to electrical grids. The purpose of deregulating the generation of electricity is to decrease the price of electricity through competition (see Rothwell and Gomez (2003)). While microeconomic studies forecasted deregulation would decrease prices 3 to 13 percent due to competition, no price reductions have been observed due to restructuring electricity markets in the United States as of 2005 (see Blumsack et al. (2005)). In addition, deregulation can cause the volatility of prices to increase see(Rothwell and Gomez (2003)). Approximately 40 percent of all electricity sold in the United States in 2005 is sold in deregulated states, therefore many electricity markets still face the possibility of becoming deregulated in the future (see Blumsack et al. (2005)). The uncertainty of future deregulation and the possible change in levels and volatility of electricity prices due to deregulation is modeled appropriately with regime shifts and jumps.

Section 3.2.4.2 and Section 3.2.4.3 develop a general real options model for wind energy investments that incorporates regime shifts and jumps. Section 3.4 presents results for two scenarios using this model. The first scenario assumes the current electricity market is regulated, but there is a possibility of it becoming deregulated in the future. The second scenario assumes the drift of the stochastic process shifts back and forth between two states due to booms and busts of oil prices.

3.2.4.2 Operating Cash Flows and Profit Function with Regime Shifts and Jumps

Regime shifts and jumps are modeled with a two-state Markov chain similarly used in Guo et al. (2005). The Markov chain $Z = (Z_t)$ with two states can be written as $Z = \begin{pmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \lambda_{22} \end{pmatrix}$, where λ_{jk} is the probability of jumping from state j to state k.

When the price of electricity follows a geometric Brownian motion with regime shifts and jumps under the equivalent martingale measure for no arbitrage pricing, $p_t = G_{j_t} e^{X_t}$, where G_j is a positive constant in each state and:

$$X_t = x + \int_0^t \mu(Z_t)dt + \int_0^t \sigma(Z_t)dW_t, \tag{3.2.47}$$

where x is the spot value of X and W is the standard Wiener process. $\mu(j) := \mu_j \in \mathbb{R}$ and $\sigma(j) := \sigma_j > 0$ are the drift and volatility of X in state j. The equivalent martingale measure is unique.

The profit function for each state can be written as:

$$\Pi_j(p_t) = \alpha_j e^{X_t^j} - \gamma + PTC \cdot Q \quad \forall t, \quad j = 1, 2, \tag{3.2.48}$$

where:

$$dX_t^j = \mu_j dt + \sigma_j dW_t, \quad j = 1, 2, \tag{3.2.49}$$

and $\alpha_j = Q \cdot G_j(1 - \tau)$.

3.2.4.3 Calculation of Investment Threshold and Investment Option Value with Regime Shifts and Jumps

A sufficient condition for the no-bubble condition in the model with regime shifts and jumps is the no-bubble condition for each state. Let $\Psi_j(z) = \mu_j z + \sigma_j^2 \frac{z^2}{2}$ be the Lévy exponent of Brownian motion X^j. The no-bubble condition is satisfied by:

$$r - \Psi_j(1) > 0 \quad j = 1, 2. \tag{3.2.50}$$

Let $g_j(X_t^j) = \alpha_j e^{X_t^j} - \gamma + PTC \cdot Q - rI$. The option value of wind energy investment with regime shifts can be written as:

$$V_j(x; h_j) = \mathrm{v}_j(x) + W_j(x; h_j), \quad j = 1, 2, \tag{3.2.51}$$

where h_j denotes the investment threshold in state j and:

$$\mathrm{v}_j(x) = \mathbb{E}^x[\int_0^\infty e^{-(r+\lambda_{jk})t}(g_j(X_t^j) + \lambda_{jk}\mathrm{v}_k(X_t^j))dt], \tag{3.2.52}$$

$$W_j(x, h_j) = \mathbb{E}^x[\int_0^{\tau_{h_j}} e^{-(r+\lambda_{jk})t}(-g_j(X_t^j) + \lambda_{jk}W_k(X_t^j; h_k))dt], \tag{3.2.53}$$

$$j = 1, 2, \quad j \neq k.$$

Using the state specific infinitesimal generator L_j, Appendix C.1.2 shows (3.2.52) can be rewritten as:

$$(r + \lambda_{jk} - L_j)\mathrm{v}_j(x) = g_j(x) + \lambda_{jk}\mathrm{v}_k(x) \quad j = 1, 2, \quad j \neq k. \tag{3.2.54}$$

For Brownian motion X^j and an arbitrary exponential function $u(x) =$

e^{zx}, the infinitesimal generator L_j and Levy exponent $\Psi_j(z)$ are related by:

$$
\begin{aligned}
L_j u(x) &= \lim_{t\to+0} \frac{\mathbb{E}^x[e^{zX_t^j}] - u(x)}{t} \\
&= \lim_{t\to+0} \frac{e^{t\Psi_j(z)}e^{zx} - e^{zx}}{t} \\
&= \Psi_j(z)e^{zx}. \qquad (3.2.55)
\end{aligned}
$$

To solve the system of equations described in (3.2.54), define matrices:

$$
A = \begin{bmatrix} r+\lambda_{12}-\Psi_1(1) & -\lambda_{12} \\ -\lambda_{21} & r+\lambda_{21}-\Psi_2(1) \end{bmatrix}, \qquad (3.2.56)
$$

$$
B = \begin{bmatrix} r+\lambda_{12} & -\lambda_{12} \\ -\lambda_{21} & r+\lambda_{21} \end{bmatrix}. \qquad (3.2.57)
$$

Define vectors:

$$
C = A^{-1} \cdot \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix}, \qquad (3.2.58)
$$

$$
D = B^{-1} \cdot \begin{bmatrix} \gamma + rI - PTC \cdot Q \\ \gamma + rI - PTC \cdot Q \end{bmatrix}, \qquad (3.2.59)
$$

where:

$$
A^{-1} = \frac{1}{\det A}\begin{bmatrix} r+\lambda_{21}-\Psi_2(1) & \lambda_{12} \\ \lambda_{21} & r+\lambda_{12}-\Psi_1(1) \end{bmatrix}, \qquad (3.2.60)
$$

$$
B^{-1} = \frac{1}{\det B}\begin{bmatrix} r+\lambda_{21} & \lambda_{12} \\ \lambda_{21} & r+\lambda_{12} \end{bmatrix}. \qquad (3.2.61)
$$

The solution for the system of equations in (3.2.54) is:

$$
\begin{bmatrix} \mathrm{v}_1(x) \\ \mathrm{v}_2(x) \end{bmatrix} = Ce^x - D. \qquad (3.2.62)
$$

The remaining part of the option value of wind energy investment shown in (3.2.51) that needs to be solved is the exit problem $W_j(x; h_j)$. Denote $W_j(x) = \sup_{h_j} W_j(x, h_j)$ for $j = 1, 2$. The optimal stopping time is

$h_j^* = \arg\sup_{h_j} W_j(x, h_j)$ for $j = 1, 2$. Similarly to what is shown in Appendix C.1.2:

$$\begin{aligned} (r + \lambda_{jk} - L_j)W_j(x) &= -g_j(x) + \lambda_{jk}W_k(x), \quad x < h_j, && (3.2.63)\\ W_j(x) &= 0, \quad x \geq h_j, && (3.2.64)\\ & j = 1, 2 \quad j \neq k. \end{aligned}$$

The boundary value problems (3.2.63) and (3.2.64) are solved numerically by using a grid described in Appendix C.1.3 and an iteration procedure found in Boyarchenko and Levedorskiĭ (2008).

Denote h_j^{*i} and $W_j^i(x)$ as the optimal investment threshold and value function in state $j = 1, 2$ during iteration step $i = 0, 1, 2, \ldots$ Suppose that $\lambda_{12} < \lambda_{21}$. Then for $i = 0$, find h_1^{*0} and $W_1^0(x)$ that solve:

$$\begin{aligned} (r - L_1)W_1^0(x) &= -g_1(x), \quad x < h_1^{*0}, && (3.2.65)\\ W_1^0(x) &= 0, \quad x \geq h_1^{*0}. && (3.2.66) \end{aligned}$$

Then find h_2^{*0} and $W_2^0(x)$ that solve:

$$\begin{aligned} (r + \lambda_{21} - L_2)W_2^0(x) &= -g_2(x) + \lambda_{21}W_1^0(x), \quad x < h_2^{*0}, && (3.2.67)\\ W_2^0(x) &= 0, \quad x \geq h_2^{*0}. && (3.2.68) \end{aligned}$$

For $i = 1, 2, \ldots$, find h_1^{*i} and $W_1^i(x)$ that solve:

$$\begin{aligned} (r + \lambda_{12} - L_1)W_1^i(x) &= -g_1(x) + \lambda_{12}W_2^{i-1}(x), \quad x < h_1^i, && (3.2.69)\\ W_1^i(x) &= 0, \quad x \geq h_1^i, && (3.2.70) \end{aligned}$$

and h_2^{*i} and $W_2^i(x)$ that solve:

$$\begin{aligned}(r + \lambda_{21} - L_2)W_2^i(x) &= -g_2(x) + \lambda_{21} W_1^i(x), \quad x < h_2^{*i}, &(3.2.71)\\ W_2^i(x) &= 0, \quad x \geq h_2^{*i}. &(3.2.72)\end{aligned}$$

Continue iteration until $\max\{|W_1^i(x) - W_1^{i-1}(x)|, |W_2^i(x) - W_2^{i-1}(x)|\} < \epsilon$, where ϵ is the desired error magnitude. Boyarchenko and Levedorskiĭ (2008) prove the iteration procedure converges to true values.

3.3 Calibration

3.3.1 Wind Energy Output Calibration

This chapter considers the investment decision of one kWh capacity. A normal utilization rate UR of 40% is used (see Welch and Venkateswaran (2009)). A period in this model is one year, therefore $Hrs = 8,760$. Q can now be calculated as:

$$\begin{aligned}Q &= UR \cdot Hrs\\ &= 40\% \cdot 8,760\\ &= 3,504 \quad kWh. &(3.3.1)\end{aligned}$$

3.3.2 Wind Energy Investment Calibration

According to Blanco (2009), the lifespan of a wind turbine is longer than 15-25 years, but at this time major maintenance costs are incurred and many parts are replaced. This chapter makes the simplifying assumption that the wind energy plant will make these repairs and never end operation. Welch and Venkateswaran (2009) estimate the investment cost per total turbine kWh capacity, denoted $CapitalCost$, of building a wind energy plant is \$1,600. This chapter assumes the total investment cost of a wind energy plant is the present value of making the initial investment, $CapitalCost$, every 25 years.

This chapter uses a discount rate of $r = 8\%$ from Welch and Venkateswaran (2009) and Gollier et al. (2005). The stochastic price process in this chapter is measured in nominal prices; furthermore, the discount rate is a nominal rate. Therefore, it is appropriate to adjust future costs by inflation. Let $\pi = .025$ be the inflation rate the plant uses to adjust future costs. The investment cost for the wind energy plant is:

$$I = \frac{CapitalCost}{1 - e^{-(r-\pi)\cdot 25}} = \$2,141.44 \tag{3.3.2}$$

3.3.3 Operating Cash Flows and Profit Function Calibration

Welch and Venkateswaran (2009) use an average variable expense of \$0.005/kWh. To adjust for inflation, I use:

$$\begin{aligned} AVE &= 0.005\frac{r}{r-\pi} = \$.0073/kWh, && (3.3.3) \\ \Rightarrow O\&M &= AVE \cdot Q = \$25.58. && (3.3.4) \end{aligned}$$

Wind energy plants apply the depreciation of their investment cost I over a 5 year depreciation schedule for tax purposes described in Welch and Venkateswaran (2009). This chapter makes the simplifying assumption that the wind energy plant smooths their depreciation cost of investment I over all future time periods for tax purposes. Therefore, the capital depreciation the plant is able to subtract from their taxable income each year is:

$$\delta = rI = \$171.32. \tag{3.3.5}$$

Following Welch and Venkateswaran (2009), the tax rate the plant faces is:

$$\tau = 40\%. \tag{3.3.6}$$

The American Recovery and Reinvestment Act of 2009 (Section 1101) extended Production Tax Credits until December 31, 2012. Currently, PTCs are provided for the first ten years of operation at the level of $\$0.022/kWh$ for renewable wind energy plants. This chapter models PTCs being provided for the lifespan of the plant, therefore an appropriate adjustment. Using the relation $\int_0^\infty e^{-rt} PTC \cdot Q dt = \int_0^{10} e^{-rt} 0.022 \cdot Q dt$, the baseline PTCs assumption is:

$$PTC = 0.022 \cdot (1 - e^{-10r}) = \$0.0121/kWh. \tag{3.3.7}$$

3.3.4 Stochastic Price Process Calibration

In the basic model without regime shifts and jumps, the price of electricity is modeled as $p_t = Ge^{X_t}$, where G is a positive constant and X is a Brownian motion with drift μ and volatility σ under the unique equivalent martingale measure for no arbitrage pricing. Using Ito's Lemma, the GBM differential equation can be written as:

$$\frac{dp_t}{p_t} = (\mu + \frac{\sigma^2}{2})dt + \sigma dW, \tag{3.3.8}$$

where $\mu + \frac{\sigma^2}{2}$ is the GBM drift.

Gollier et al. (2005) and Bellamy and Sahut (2007) are two papers that model electricity prices as GBM. Gollier et al. (2005) analyze volatility levels of $\sigma = 10\%$ and $\sigma = 20\%$ and Bellamy and Sahut (2007) use a volatility level of $\sigma = 20\%$. The baseline volatility assumption used in the basic model without regime shifts and jumps is $\sigma = 10\%$ in order to present a conservative estimate of the errors using a NPV rule model. Multiple volatility values ranging from 5% to 25% are considered in Section 3.4.

Gollier et al. (2005) set the GBM drift to zero and Bellamy and Sahut (2007) use set the GBM drift to $\mu + \frac{\sigma^2}{2} = .05 \Rightarrow \mu = .03$. The baseline Brownian motion drift assumption used in the basic model without regime shifts and jumps is $\mu = 0.02$. Therefore, the baseline GBM drift assumption used in the basic model without regime shifts and jumps is $\mu + \frac{\sigma^2}{2} = 0.020 + \frac{0.1^2}{2} = 0.025$. This chapter also considers multiple values of the GBM drift assumption in Section 3.4. The GBM drift is discussed in Section 3.4 rather than μ because $\mathbb{E}[p_{t+h}|h] = p_t e^{(\mu + \frac{\sigma^2}{2})h}$ for $h > 0$. When the level of volatility is varied, the GBM drift is held constant in order to preserve the same NPV of the investment in order to isolate the effect of risk on investment decisions.

A wholesale price spot value of $x = 0$ and $G = \$0.04/kWh$ is used from Welch and Venkateswaran (2009) for the basic model without regime shifts and jumps: $p_0 = Ge^x = \$0.04/kWh$.

Two scenarios are analyzed in Section 3.4 using the model with regime shifts and jumps. The first scenario assumes the current electricity market is regulated, but there is a possibility of it becoming deregulated in the future. This is modeled by assuming the price of electricity starts in state 1, where $x = 0$, $G_1 = \$0.04/kWh$, $\mu_1 = .020$, and $\sigma_1 = 10\%$. Deregulation is expected to occur in $\frac{1}{\lambda_{12}}$ years causing a jump in the electricity price of size $\zeta \cdot 100\% \leq 0$ and an increase in volatility: $G_2 = (1+\zeta) \cdot G_1$ and $\sigma_2 = 20\%$. In order to keep the GBM drift equal between the two states, $\mu_2 + \frac{0.2^2}{2} = 0.20 + \frac{0.1^2}{2} \Rightarrow \mu_2 = .005$. Although prices theoretically should decrease after deregulation, Blumsack et al. (2005) find no price reductions have been observed due to deregulation. Thus, the baseline value for the jump is $\zeta = 0 \Rightarrow G_2 = \$0.04/kWh$. Multiple values of ζ are considered in Section 3.4. The baseline value $\lambda_{12} = \frac{1}{6 \text{ years}}$ is used for λ_{12} implying an expected 6 years before deregulation occurs. Multiple values of λ_{12} are also considered in Section 3.4. It is assumed that once the electricity market becomes deregulated, it will stay deregulated, therefore $\lambda_{21} = 0$.

The second scenario analyzed using the model with regime shifts and jumps is the GBM drift of the electricity price shifting back and forth between two regimes due to booms and busts of oil prices. The correlation between future oil and electricity prices can be caused by direct market interactions or government policies encouraging electricity energy in order to become oil independent. Figure 3.1 shows that electricity prices increase sharply when oil prices increase sharply, but stay relatively level when oil prices drop.

Let state 1 represent electricity prices staying level and state 2 represent

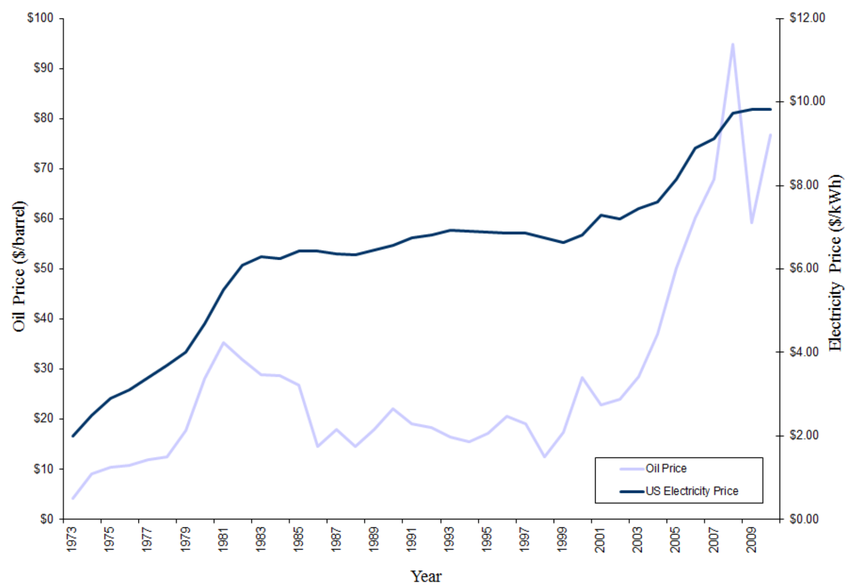

Figure 3.1: Historical Annual Oil and Retail Electricity Prices: 1973-2010

electricity prices sharply increasing. To determine baseline values for λ_{12} and λ_{21}, yearly electricity prices from 1973-2008 obtained from the Department of Energy's Energy Information Center are used. Although the data does not extend earlier than 1973, Pindyck (1999) states there was a structural change in oil prices in the year 1973. Therefore, it is reasonable to expect there was also a structural change in the price of electricity in 1973. Looking at historical prices of electricity, other structural changes occur in 1982, 2000, and 2008. The length of time during 1982-1999 is used to calculate the baseline assumption $\lambda_{12} = \frac{1}{18 \text{ years}} = 0.0556$ and the length of time during 1973-1981 is used to calculate the baseline assumption $\lambda_{21} = \frac{1}{9 \text{ years}} = 0.1111$. The sharp increase in prices for 9 years during 2000-2008 adds support for the baseline assumption of λ_{21}. Multiple levels of λ_{12} and λ_{21} are considered in Section

3.4. The volatility is assumed to be the same in each state, $\sigma_1 = \sigma_2 = 10\%$, and there are no jumps in the price process, $x = 0$ and $\zeta = 0 \Rightarrow G_2 = G_2 = \$0.04/kWh$. $\mu_1 = 0$ is used for state 1 and $\mu_2 = 0.05$ is used for state 2.

3.4 Results

3.4.1 Basic Model with and without Production Tax Credits Results

Table 3.1 presents the investment threshold price $p^* = G^{h^*}$, the option value, and the NPV of investing in one unit of electricity for different GBM drift and volatility assumptions when PTCs are $\$0.022/kWh$[3]. The NPV of the investment does not depend on the volatility of electricity prices, but the option value increases with respect to the volatility assumption to reflect higher price levels are achievable with more volatility. The investment threshold price increases with volatility because the benefit of waiting for uncertainty to resolve is greater with higher levels of volatility. Thus, more volatility in electricity prices will delay wind energy investment, but will increase the value of the option to invest in wind energy.

The current PTCs level of $\$0.022/kWh$ is not large enough to encourage investors to invest in wind energy immediately even though the NPV of the investment is \$584 when using baseline parameter values of $\sigma = 20\%$ and $\mu + \frac{\sigma^2}{2} = 0.025 \Rightarrow \mu = 0.02$. Figure C.1 in Appendix C.2.1 shows the investment

[3]The GBM drift, $\mu + \frac{\sigma^2}{2}$, depends on the volatility; therefore μ changes as you move from left to right in Table 3.1 and Table 3.2 in order to keep the GBM drift constant.

GBM		Volatility			
Drift		5%	10%	15%	20%
0.0000	Threshold Price	0.0408	0.0462	0.0522	0.0590
	Option Value	107	140	181	224
	NPV	106	106	106	106
0.0125	Threshold Price	0.0386	0.0434	0.0492	0.0557
	Option Value	301	310	342	382
	NPV	301	301	301	301
0.0250	Threshold Price	0.0376	**0.0415**	0.0467	0.0529
	Option Value	584	**585**	604	637
	NPV	584	**584**	584	584
0.0375	Threshold Price	0.0371	0.0403	0.0448	0.0504
	Option Value	1,033	1,033	1,043	1,067
	NPV	1,033	1,033	1,033	1,033
0.0500	Threshold Price	0.0369	0.0394	0.0433	0.0484
	Option Value	1,858	1,858	1,862	1,878
	NPV	1,858	1,858	1,858	1,858

Table 3.1: Investment Threshold Price, Option Value, Net Present Value; $0.022/kWh$ PTCs

threshold and investment option value under different levels of PTCs using baseline assumptions for other parameters in the basic model without regime shifts and jumps. The lowest level of PTCs that induce immediate investment in wind energy is $.0235/kWh$, which is 7 percent higher than the current level. Table 3.1 shows the price volatility would need to decrease to $\sigma = 5\%$ when the GBM drift is 0.025 in order for the investment threshold price to be below the current spot price. If the GBM drift assumption increased to 0.05, immediate investment would occur if the volatility was less than or equal to 10%.

Welch and Venkateswaran (2009) conclude that PTCs could be lowered to $0.01/kWh$ and plants would still immediately invest using the naive NPV rule. Results in Table 3.1 show that even when the NPV of an investment is positive, potential wind energy plants may delay investment to resolve uncertainty. In fact, the NPV of the investment is positive for all values of GBM drift and volatility considered in Table 3.1 even though only 5 out of the 20 parameter combinations would result in immediate investment when PTCs are $0.022/kWh$.

Table 3.2 presents the investment threshold price, the option value, and the NPV of investing in one unit of electricity for different GBM drift and volatility assumptions in the absence of PTCs. Under baseline values of GBM drift and volatility, the NPV of the investment in the absence of PTCs is $53 > 0$, but the investment threshold price is $0.0648/kWh$. The expected time of investment, known as the stopping time, is greater than 24 years away when the investment threshold price is $\$0.0648/kWh$. The fact that Welch and Venkateswaran (2009) calculate a negative NPV for wind energy investment in the absence of PTCs implies that the difference between Welch and Venkateswaran (2009) concluding PTCs could be lowered to $\$0.01/kWh$ and my results concluding that PTCs need to be raised to $\$0.0235/kWh$ is due to Welch and Venkateswaran (2009) ignoring the option to delay investment and not due to my model using less favorable parameters. Not only do baseline assumptions not cause immediate investment in the absence of PTCs, but no GBM drift and volatility combination considered in Table 3.2 would cause immediate investment in the absence of PTCs.

Future technology improvements can reduce capital costs and improve utilization rates, therefore it is important to understand how these improvements affect the necessity for PTCs (see Blanco (2009)). My results also differ greatly from Welch and Venkateswaran (2009) when considering the ability to remove PTCs if there are significant cost or efficiency improvements. Welch and Venkateswaran (2009) state that PTCs can be completely removed if $CapitalCost \leq \$1,200$. Figure C.5 in Appendix C.2.2 shows the investment threshold and investment option value under different $CapitalCost$ assumptions using baseline assumptions for other parameters in the basic model without regime shifts and jumps and setting $PTC = 0$. Some level of PTCs is needed for immediate investment even when $CapitalCost = \$1,000/kWh$. In fact, capital costs need to be reduced to $CapitalCost = \$895/kWh$ in order to induce immediate investments without PTCs. This is a 44 percent decrease

GBM		Volatility			
Drift		5%	10%	15%	20%
0.0000	Threshold Price	0.0636	0.0721	0.0815	0.0921
	Option Value	4	29	68	112
	NPV	-425	-425	-425	-425
0.0125	Threshold Price	0.0603	0.0678	0.0768	0.0870
	Option Value	59	110	167	224
	NPV	-230	-230	-230	-230
0.0250	Threshold Price	0.0587	**0.0648**	0.0729	0.0825
	Option Value	251	**304**	366	431
	NPV	53	**53**	53	53
0.0375	Threshold Price	0.0580	0.0628	0.0699	0.0788
	Option Value	648	691	749	813
	NPV	503	503	503	503
0.0500	Threshold Price	0.0575	0.0615	0.0676	0.0756
	Option Value	1,441	1,473	1,522	1,582
	NPV	1,327	1,327	1,327	1,327

Table 3.2: Investment Threshold Price, Option Value, Net Present Value; No PTCs

from the current cost level, therefore it is unrealistic that cost improvements alone can induce immediate investment without PTCs.

Similarly, reasonable efficiency improvements will not induce immediate investment without the assistance of PTCs. Welch and Venkateswaran (2009) state that PTCs can be completely removed if $UR \geq 53\%$. Figure C.9 in Appendix C.2.3 shows the investment threshold and investment option value under different UR assumptions using baseline assumptions for other parameters in the basic model without regime shifts and jumps and setting $PTC = 0$. Some level of PTCs is needed for immediate investment even when $UR = 60\%$. In fact, utilization rates need to increase to $UR = 71\%$ in order to induce immediate investments without PTCs. This is a 77.5 percent increase from the current utilization rate. A large portion of utilization rates depend on the weather, therefore it is unrealistic that efficiency improvements alone can induce immediate investment without PTCs.

Different cost improvement and turbine efficiency combinations are analyzed. Improving the efficiency to $UR = 45\%$ requires $CapitalCost \leq \$1,008/kWh$ to induce investment in the current period without PTCs. Improving the efficiency to $UR = 50\%$ requires $CapitalCost \leq \$1,120/kWh$ and $UR = 55\%$ requires $CapitalCost \leq \$1,230/kWh$ when $PTC = 0$. It is unlikely that utilization rates would increase by 37.5 percent and capital costs would decrease by 23 percent such that $UR = 55\%$ and $CapitalCost = \$1,230/kWh$. Therefore, PTCs are still needed to induce immediate investment under reasonable cost and efficiency improvements.

3.4.2 Model with Regime Shifts and Jumps Results

The first scenario analyzed using the model with regime shifts and jumps is a possibility of the electricity market becoming deregulated in the future. Table 3.3 shows the investment threshold price, option value, and NPV for the investment of one unit of electricity using different values of λ_{12} and various jump levels in the price process when PTCs are $\$0.022/kWh$. Baseline assumptions are $G_1 = \$0.04/kWh$, $\zeta = 0 \Rightarrow G_2 = \$0.04/kWh$, $\sigma_1 = 10\%$, $\sigma_2 = 20\%$, $\mu_1 + \frac{\sigma_1^2}{2} = \mu_2 + \frac{\sigma_2^2}{2} = .025$, and $\lambda_{21} = 0$.

Under no level of ζ and λ_{12} is the current PTCs level large enough for immediate investment. Intuitively, the investment threshold is inversely related to ζ, whereas the option value and NPV of the investment are increasing with respect to ζ. The NPV of the investment is not affected by the increase in volatility in state 2, therefore the NPV of the investment is non-increasing with respect to λ_{12}. The relationship between the option value and λ_{12} depends on the size of the jump. The negative jump in the price in the state 2 decreases the value of the investment option, but the increase in volatility increases the investment option. For smaller jumps in magnitude, the effect of a higher volatility in state 2 outweighs the effect of a negative jump in the electricity prices and the option value is increasing with respect to λ_{12}. For more negative jumps, the relationship between λ_{12} and the option value is non-monotonic. As λ_{12} initially decreases, the option value decreases reflecting the volatility effect. But at a certain level of λ_{12}, the option value increases as λ_{12} decreases reflecting the jump effect.

Jump		λ_{12}				
ζ		$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{6}$	$\frac{1}{8}$	$\frac{1}{10}$
0.0%	Investment Threshold	0.0468	0.0454	**0.0447**	0.0442	0.0438
	Option Value	614	604	**599**	596	594
	NPV	584	584	**584**	584	584
-2.5%	Investment Threshold	0.0475	0.0460	0.0451	0.0446	0.0442
	Option Value	585	577	573	572	571
	NPV	549	552	555	557	559
-5.00%	Investment Threshold	0.0482	0.0465	0.0456	0.0450	0.0445
	Option Value	557	550	547	547	548
	NPV	515	521	526	531	534
-7.50%	Investment Threshold	0.0490	0.0471	0.0461	0.0454	0.0448
	Option Value	530	523	522	524	526
	NPV	480	490	497	504	510
-10.00%	Investment Threshold	0.0498	0.0477	0.0466	0.0458	0.0452
	Option Value	503	497	498	500	504
	NPV	446	458	469	477	485
-12.50%	Investment Threshold	0.0507	0.0484	0.0471	0.0462	0.0456
	Option Value	477	472	473	477	482
	NPV	411	427	440	451	460

Table 3.3: Investment Threshold Price, Option Value, Net Present Value; Deregulation

Figure C.2 in Appendix C.2.1 shows the investment threshold and investment option value under different levels of PTCs using baseline assumptions for other parameters in the model representing deregulation. The lowest level of PTCs that induce immediate investment in wind energy is $\$.0261/kWh$, which is 18.6 percent higher than the current level.

Figure C.6 in Appendix C.2.2 shows the investment threshold and investment option value under different $CapitalCost$ assumptions using baseline assumptions for other parameters in the model representing deregulation and setting $PTC = 0$. As shown, when $CapitalCost = \$1,000/kWh$, PTCs are still needed for immediate investment. In fact, capital costs need to be reduced to $CapitalCost = \$818/kWh$ in order to induce immediate investments without PTCs. This is a 49 percent decrease from the current cost level, therefore it is unrealistic that cost improvements alone can induce immediate investment without PTCs.

Figure C.10 in Appendix C.2.3 shows the investment threshold and investment option value under different UR assumptions using baseline assumptions for other parameters in the model representing deregulation and setting $PTC = 0$. As shown, when $UR = 60\%$, PTCs are still needed for immediate investment. In fact, utilization rates need to increase to $UR = 78\%$ in order to induce immediate investments without PTCs. This is a 95 percent increase from the current utilization rate, therefore it is unrealistic that efficiency improvements alone can induce immediate investment without PTCs.

Different cost improvement and turbine efficiency combinations are analyzed. Improving the efficiency to $UR = 45\%$ requires $CapitalCost \leq \$918/kWh$ to induce investment in the current period without PTCs. Improving the efficiency to $UR = 50\%$ requires $CapitalCost \leq \$1,020/kWh$ and $UR = 55\%$ requires $CapitalCost \leq \$1,123/kWh$ when $PTC = 0$. Therefore, PTCs are still needed to induce immediate investment under reasonable cost and efficiency improvements.

The second scenario analyzed using the model with regime shifts and jumps is the GBM drift of the electricity price shifting back and forth between two regimes due to booms and busts of oil prices. Table 3.4 and Table 3.5 show the investment threshold price, option value, and NPV for the investment of one unit of electricity in state 1 and state 2 respectively when PTCs are $0.022/kWh$. Both Table 3.4 and Table 3.5 use baseline assumptions $G_1 = G_2\$0.04/kWh$, $\sigma_1 = \sigma_2 = 10\%$, and $\mu_1 + \frac{\sigma_1^2}{2} = \mu_2 + \frac{\sigma_2^2}{2} = .025$. Baseline assumptions also include $\lambda_{12} = \frac{1}{18}$ and $\lambda_{21} = \frac{1}{9}$. Multiple values of λ_{12} and λ_{21} are considered.

Because the two states only differ by a more favorable GBM drift in state 2, the investment threshold is lower in state 2 and the option value and NPV is higher in state 2. As expected, the investment threshold is decreasing with respect to λ_{12} and increasing with respect to λ_{21} in both states. Furthermore, the option value and NPV of the investment are increasing with respect to λ_{12} and decreasing with respect to λ_{21} in both states.

Under no assumption of λ_{21} and λ_{12} is the current PTCs level large enough for immediate investment in either state. Figure C.3 and Figure C.4

λ_{12}		λ_{21} $\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{9}$	$\frac{1}{12}$	$\frac{1}{15}$
$\frac{1}{12}$	Investment Threshold	0.0447	0.0444	0.0442	0.0441	0.0440
	Option Value	264	362	438	498	547
	NPV	245	346	423	485	534
$\frac{1}{15}$	Investment Threshold	0.0450	0.0447	0.0445	0.0444	0.0443
	Option Value	240	322	386	438	481
	NPV	219	303	370	422	466
$\frac{1}{18}$	Investment Threshold	0.0451	0.0448	**0.0447**	0.0446	0.0446
	Option Value	224	294	**350**	396	434
	NPV	201	274	**331**	378	416
$\frac{1}{21}$	Investment Threshold	0.0453	0.0450	0.0449	0.0448	0.0447
	Option Value	212	273	323	364	398
	NPV	188	252	303	344	379
$\frac{1}{24}$	Investment Threshold	0.0454	0.0451	0.0450	0.0449	0.0449
	Option Value	203	257	302	339	370
	NPV	178	235	280	318	350

Table 3.4: Investment Threshold Price, Option Value, Net Present Value; Booms and Busts in Oil Prices State 1

λ_{12}		λ_{21} $\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{9}$	$\frac{1}{12}$	$\frac{1}{15}$
$\frac{1}{12}$	Investment Threshold	0.0426	0.0415	0.0410	0.0406	0.0404
	Option Value	382	578	729	848	945
	NPV	378	577	728	848	945
$\frac{1}{15}$	Investment Threshold	0.0427	0.0416	0.0411	0.0408	0.0405
	Option Value	359	542	687	803	898
	NPV	354	541	686	802	898
$\frac{1}{18}$	Investment Threshold	0.0429	0.0418	**0.0412**	0.0408	0.0406
	Option Value	343	517	**657**	770	864
	NPV	338	515	**656**	770	864
$\frac{1}{21}$	Investment Threshold	0.0429	0.0418	0.0413	0.0409	0.0407
	Option Value	332	499	634	745	838
	NPV	326	497	633	745	838
$\frac{1}{24}$	Investment Threshold	0.0430	0.0419	0.0413	0.0410	0.0407
	Option Value	323	485	617	726	818
	NPV	317	482	616	726	818

Table 3.5: Investment Threshold Price, Option Value, Net Present Value; Booms and Busts in Oil Prices State 2

in Appendix C.2.1 show the investment threshold and investment option value under different levels of PTCs using baseline assumptions for other parameters in the model representing boom and busts of oil prices. The lowest level of PTCs that induce immediate investment in wind energy in state 1 is $\$.0258/kWh$, which is 17.3 percent higher than the current level. The lowest level of PTCs that induce immediate investment in wind energy in state 2 is $\$.0230/kWh$, which is 4.5 percent higher than the current level.

Figure C.7 and Figure C.8 in Appendix C.2.2 show the investment threshold and investment option value under different $CapitalCost$ assumptions using baseline assumptions for other parameters in the model representing boom and busts of oil prices and setting $PTC = 0$. PTCs are needed for immediate investment in either state when $CapitalCost = \$1,000/kWh$. In fact, capital costs need to be reduced to $CapitalCost = \$824/kWh$ in state 1 and $CapitalCost = \$911/kWh$ in state 2 in order to induce immediate investments without PTCs. This is a 48.5 percent and 43 percent decrease respectively from the current cost level, therefore it is unrealistic that cost improvements alone can induce immediate investment without PTCs.

Figure C.11 and Figure C.12 in Appendix C.2.3 show the investment threshold and investment option value under different UR assumptions using baseline assumptions for other parameters in the model representing boom and busts of oil prices and setting $PTC = 0$. PTCs are needed for immediate investment in either state when $UR = 60\%$. In fact, utilization rates need to increase to $UR = 78\%$ in state 1 and $UR = 70\%$ in state 2 in order to induce immediate investments without PTCs. This is a 95 percent and 75 percent increase respectively from the current utilization rate, therefore it is unrealistic that efficiency improvements alone can induce immediate investment without PTCs.

Different cost improvement and turbine efficiency combinations are analyzed. Improving the efficiency to $UR = 45\%$ requires $CapitalCost \leq \$929/kWh$ in state 1 and $CapitalCost \leq \$1,025/kWh$ in state 2 to induce investment in the current period without PTCs. Improving the efficiency to $UR = 50\%$ requires $CapitalCost \leq \$1,031/kWh$ in state 1 and $CapitalCost \leq \$1,139/kWh$ in state 2. Improving the efficiency to $UR = 55\%$ requires $CapitalCost \leq \$1,136/kWh$ in state 1 $CapitalCost \leq \$1,253/kWh$ in state 2. The current regime is state 1, therefore, PTCs are still needed to induce immediate investment under reasonable cost and efficiency improvements. If the current environment were to switch to a boom in oil prices, the improvements in utilization rate and capital cost are still greater than what can likely occur.

3.5 Conclusion

This chapter analyzed the investment decision of a wind energy plant based on investment cost, production efficiency, government policy, current price of electricity, and beliefs on future electricity prices. In contrast to Welch and Venkateswaran (2009), who argue PTCs can be lowered to $\$0.01/kWh$, my results showed that potential wind energy plants will most likely not invest even at current PTCs levels of $0.022/kWh$. Although the NPV of the investment is positive using baseline assumptions, potential wind energy plants will defer their decision in order to resolve uncertainty. The basic model in this chapter predicted a PTCs level of $0.0235/kWh$ is needed to induce immediate investment in wind energy.

In addition to a basic model using geometric Brownian motion, this chapter analyzed two scenarios using a stochastic price process with regime shifts and jumps. The first scenario assumed the current electricity market is regulated, but there is a possibility of it becoming deregulated in the future. The second scenario assumed the GBM drift of the electricity price shifts back and forth between two regimes due to booms and busts of oil prices. In both scenarios, the current level of PTCs is not great enough for immediate investment in wind energy.

Welch and Venkateswaran (2009) state that PTCs may be removed with reasonable cost and efficiency improvements, but my results using a real options model showed otherwise. Multiple cost and efficiency scenarios were analyzed under the different models. In all cases, the improvements in cost and efficiency are greater than what is reasonable.

In addition to providing useful results for policy makers encouraging renewable energy, this chapter clearly shows a real options model is necessary to analyze the need for PTCs in wind energy. Furthermore, it shows the errors obtained using the NPV rule to analyze an irreversible investment under uncertainty is large and cannot be overlooked.

Appendices

Appendix A

A.1 Summary of Eight Cases Examined

1. Traditional Fee Structure; NFB^m growth depends on $X^m(1)$
2. Performance-Based Fee Structure; NFB^m growth depends on $X^m(1)$
3. Traditional Fee Structure; NFB^m growth depends on relative value of $X^m(1)$ compared to $X^{-m}(1)$
4. Performance-Based Fee Structure; NFB^m growth depends on relative value of $X^m(1)$ compared to $X^{-m}(1)$
5. Traditional Fee Structure; NFB^m growth depends on $\hat{\theta}_m$
6. Performance-Based Fee Structure; NFB^m growth depends on $\hat{\theta}_m$
7. Traditional Fee Structure; NFB^m growth depends on relative value of $\hat{\theta}_m$ compared to $\hat{\theta}_{-m}$
8. Performance-Based Fee Structure; NFB^m growth depends on relative value of $\hat{\theta}_m$ compared to $\hat{\theta}_{-m}$

A.2 List of Variables

Variable	Description
t	Time; $t = 0, 1, 2$
$\omega(t)$	State of the world at time t; $\omega(t) = \omega_{G_t}$ or ω_{B_t}
m	Fund manager; $m = 1, 2$
l	Fund manager to choose investment first at $t = 1$; $l = 1, 2$
$C^m(t)$	Fund Manager m investment choice; $C =$ Investment R_t^m or Investment S_t^m
$X^m(C, \omega, t)$	The $t-1$ to t period investment return for Fund Manager m; $X = r_G, r_B$, or r
r	Risk-free rate
π	Risk premium for Investment R
$S^m(t)$	Private signal observed by Fund Manager m at time t; $S = S_{G_t}^m$ or $S_{B_t}^m$
θ	Unconditional probability that a fund manager is talented
$\hat{\theta}_m$	Updated posterior probability that Fund Manager m is talented
T_m	Notation for Fund Manager m being talented
U_m	Notation for Fund Manager m being untalented
p	Probability a talented fund manager observes S_G given ω_{G_1}; $p = \mathbb{P}(S_G \vert \omega_{G_1}, T)$
$1 - p$	Probability a talented fund manager observes S_G given ω_{B_1}; $1 - p = \mathbb{P}(S_G \vert \omega_{B_1}, T)$
$MFRT$	Management fee percentage rate in a traditional fee structure
$MFRP$	Management fee percentage rate in a performance-based fee structure
PF	Performance fee percentage rate in a performance-based fee structure
$NFB^m(t)$	Net fund balance at time t for Fund Manager m
$\hat{nfb}$	Endowed NFB at $t = 0$
$MFT^m(t)$	Management fees raised in a traditional fee structure by Fund Manager m at time t; $MFT = MFRT \cdot NFB$
$MFP^m(t)$	Management fees raised in a performance-based fee structure by Fund Manager m at time t; $MFP = MFRP \cdot NFB$
$PF^m(t, X)$	Performance fees raised in a performance-based fee structure by Fund Manager m at time t; $PF = PFR \cdot X \cdot NFB$

Table A.1: List of Variables

A.3 Calculations

A.3.1 Calculations Involving One Private Signal and State of the World

This section shows calculations for the posterior probabilities of being the talented type and conditional state probabilities involving only one private signal and state of the world in the information set.

Given that a fund manager does not know what type she is, using Bayes' Law she calculates the following probabilities for state ω_{G_1} occurring at the end of the period when conditioning only on her private signal:

$$\begin{aligned}
\mathbb{P}(\omega_{G_1}|S^m_{G_0}) &= \mathbb{P}(\omega_{B_1}|S^m_{B_0}) \\
&= \frac{[\theta p + (1-\theta)\frac{1}{2}]}{\frac{1}{2}} \cdot \frac{1}{2}, \\
&= \frac{1}{2} + \theta(p - \frac{1}{2}), \qquad \text{(A.3.1)} \\
\mathbb{P}(\omega_{G_1}|S^m_{B_0}) &= \mathbb{P}(\omega_{B_1}|S^m_{G_0}) \\
&= \frac{[\theta(1-p) + (1-\theta)\frac{1}{2}]}{\frac{1}{2}} \cdot \frac{1}{2}, \\
&= \frac{1}{2} + \theta(\frac{1}{2} - p). \qquad \text{(A.3.2)}
\end{aligned}$$

Let $\hat{\theta}^*_m(S^m_{G_0}, \omega_{G_1})$ denote the posterior probability that Fund Manager m is talented given $S^m(0) = S^m_{G_0}$ and $\omega(t) = \omega_{G_1}$ occurs. Using Bayes' Law,

$$\begin{aligned}
\hat{\theta}^*_m(S^m_{G_0}, \omega_{G_1}) &= \frac{\frac{1}{2}\theta p}{\frac{1}{2}\theta p + \frac{1}{4}(1-\theta)} \\
&= \frac{2\theta p}{2\theta p + (1-\theta)}. \qquad \text{(A.3.3)}
\end{aligned}$$

(A.3.4)

The numerator represents the probability of Fund Manager m being talented, observing $S^m_{G_0}$ and state ω_{G_1} occurring. The prior probability of Fund Manager m being talented is simply θ. Given that Fund Manager m is talented, the probability of state ω_{G_1} occurring and her observing $S^m_{G_0}$ is $\frac{1}{2}p$. The denominator also includes the probability of Fund Manager m being untalented, observing $S^m_{G_0}$, and state ω_{G_1} occuring. The prior probability of Fund Manager m being untalented is $1-\theta$. Given that Fund Manager m is untalented, the probability of state ω_{G_1} occuring and her observing $S^m_{G_0}$ is $\frac{1}{2}\cdot\frac{1}{2}=\frac{1}{4}$. By symmetry,

$$\begin{aligned}\hat{\theta}^*_m(S^m_{G_0},\omega_{G_1}) &= \hat{\theta}^*_m(S^m_{B_0},\omega_{B_1}) \\ &= \frac{2\theta p}{2\theta p+(1-\theta)}. \qquad \text{(A.3.5)} \\ & \qquad \text{(A.3.6)}\end{aligned}$$

Similarly,

$$\begin{aligned}\hat{\theta}^*_m(S^m_{G_0},\omega_{B_1}) &= \hat{\theta}^*_m(S^m_{B_0},\omega_{G_1}) \\ &= \frac{2\theta(1-p)}{2\theta(1-p)+(1-\theta)}. \qquad \text{(A.3.7)}\end{aligned}$$

Additional calculations involving one private signal and the state of the world are:

$$\begin{aligned}
\mathbb{P}(S_{G_0}^{-m},\omega_{G_1}|S_{G_0}^{m}) &= \mathbb{P}(S_{B_0}^{-m},\omega_{B_1}|S_{B_0}^{m}) \\
&= \frac{\mathbb{P}(\omega_{G_1}|S_{G_0}^{m},S_{G_0}^{-m})\cdot\mathbb{P}(S_{G_0}^{m},S_{G_0}^{-m})}{\mathbb{P}(S_{G_0}^{m})} \\
&= \frac{\frac{4\theta p+(1-\theta)^2}{4\theta+2(1-\theta)^2}\cdot\frac{1}{4}(1+\theta^2)}{\frac{1}{2}} \\
&= \theta p+\frac{1}{4}(1-\theta)^2, && \text{(A.3.8)} \\
\mathbb{P}(S_{G_0}^{-m},\omega_{B_1}|S_{G_0}^{m}) &= \mathbb{P}(S_{B_0}^{-m},\omega_{G_1}|S_{B_0}^{m}) \\
&= \frac{\mathbb{P}(\omega_{B_1}|S_{G_0}^{m},S_{G_0}^{-m})\cdot\mathbb{P}(S_{G_0}^{m},S_{G_0}^{-m})}{\mathbb{P}(S_{G_0}^{m})} \\
&= \frac{\frac{4\theta(1-p)+(1-\theta)^2}{4\theta+2(1-\theta)^2}\cdot\frac{1}{4}(1+\theta^2)}{\frac{1}{2}} \\
&= \theta(1-p)+\frac{1}{4}(1-\theta)^2, && \text{(A.3.9)} \\
\mathbb{P}(S_{B_0}^{-m},\omega_{G_1}|S_{G_0}^{m}) &= \mathbb{P}(S_{B_0}^{-m},\omega_{B_1}|S_{G_0}^{m}) \\
&= \mathbb{P}(S_{G_0}^{-m},\omega_{G_1}|S_{B_0}^{m})=\mathbb{P}(S_{G_0}^{-m},\omega_{B_1}|S_{B_0}^{m}) \\
&= \frac{\mathbb{P}(\omega_{G_1}|S_{G_0}^{m},S_{B_0}^{-m})\cdot\mathbb{P}(S_{G_0}^{m},S_{B_0}^{-m})}{\mathbb{P}(S_{G_0}^{m})} \\
&= \frac{\frac{1}{2}\cdot\frac{1}{4}(1-\theta^2)}{\frac{1}{2}} \\
&= \frac{1}{4}(1-\theta^2). && \text{(A.3.10)}
\end{aligned}$$

A.3.2 Calculations Involving Both Private Signals and State of the World

This section shows calculations for the posterior probabilities of being the talented type and conditional state probabilities involving both private signals and state of the world in the information set.

$$
\begin{aligned}
\mathbb{P}(\omega_{G_1}|S^1_{B_0},S^2_{G_0}) &= \mathbb{P}(\omega_{G_1}|S^1_{G_0},S^2_{B_0}) \\
&= 1-\mathbb{P}(\omega_{B_1}|S^1_{B_0},S^2_{G_0}) = 1-\mathbb{P}(\omega_{B_1}|S^1_{G_0},S^2_{B_0}) \\
&= \frac{\mathbb{P}(S^1_{B_0},S^2_{G_0}|\omega_{G_1})\mathbb{P}(\omega_{G_1})}{\mathbb{P}(S^1_{B_0},S^2_{G_0}|\omega_{G_1})\mathbb{P}(\omega_{G_1})+\mathbb{P}(S^1_{B_0},S^2_{G_0}|\omega_{B_1})\mathbb{P}(\omega_{B_1})} \\
&= \frac{\frac{1}{2}[\frac{1}{2}p\theta(1-\theta)+\frac{1}{2}(1-p)\theta(1-\theta)+\frac{1}{4}(1-\theta)^2]}{\frac{1}{2}[p\theta(1-\theta)+(1-p)\theta(1-\theta)+\frac{1}{2}(1-\theta)^2]} \\
&= \frac{1}{2}, \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (A.3.11) \\
\mathbb{P}(\omega_{G_1}|S^1_{B_0},S^2_{B_0}) &= \mathbb{P}(\omega_{B_1}|S^1_{G_0},S^2_{G_0}) \\
&= 1-\mathbb{P}(\omega_{B_1}|S^1_{B_0},S^2_{B_0}) = 1-\mathbb{P}(\omega_{G_1}|S^1_{G_0},S^2_{G_0}) \\
&= \frac{\mathbb{P}(S^1_{B_0},S^2_{B_0}|\omega_{G_1})\mathbb{P}(\omega_{G_1})}{\mathbb{P}(S^1_{B_0},S^2_{B_0}|\omega_{G_1})\mathbb{P}(\omega_{G_1})+\mathbb{P}(S^1_{B_0},S^2_{B_0}|\omega_{B_1})\mathbb{P}(\omega_{B_1})} \\
&= \frac{4\theta(1-p)+(1-\theta)^2}{4\theta+2(1-\theta)^2}, \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (A.3.12) \\
\Rightarrow \mathbb{P}(\omega_{B_1}|S^1_{B_0},S^2_{B_0}) &= \mathbb{P}(\omega_{G_1}|S^1_{G_0},S^2_{G_0}) \\
&= \frac{4\theta p+(1-\theta)^2}{4\theta+2(1-\theta)^2}, \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (A.3.13)
\end{aligned}
$$

where $\mathbb{P}(S^1_{B_0},S^2_{B_0}|\omega_{G_1})\mathbb{P}(\omega_{G_1}) = \frac{1}{2}[\frac{1}{4}(1-\theta)^2+(1-p)(1-\theta)\theta+(1-p)\theta^2]$ and $\mathbb{P}(S^1_{B_0},S^2_{B_0}|\omega_{G_1})\mathbb{P}(\omega_{G_1})+\mathbb{P}(S^1_{B_0},S^2_{B_0}|\omega_{B_1})\mathbb{P}(\omega_{B_1}) = \frac{1}{2}[\frac{1}{2}(1-\theta)^2+(1-p)(1-\theta)\theta+(1-p)\theta^2+p\theta^2+p(1-\theta)\theta]$.

Let $\hat{\theta}^{**}_m(S^{-m}_{B_0},S^m_{G_0},\omega_{G_1})$ denote the posterior probability that Fund Manager m is talented given $S^{-m}(0)=S^{-m}_{B_0}$, $S^m(0)=S^m_{G_0}$, and $\omega(1)=\omega_{G_1}$. Using

Bayes' Law,

$$
\begin{aligned}
\hat{\theta}^{**}_m(S^{-m}_{B_0}, S^m_{G_0}, \omega_{G_1}) &= \frac{\frac{1}{2}p\theta(1-\theta)}{\frac{1}{2}p\theta(1-\theta)+\frac{1}{2}(1-p)\theta(1-\theta)+\frac{1}{4}(1-\theta)^2} \\
&= \frac{2\theta p}{1+\theta}. \qquad \text{(A.3.14)}
\end{aligned}
$$

To understand (A.3.14), there are three possible combinations of fund manager ability: (U_{-m}, T_m), (T_{-m}, U_m), and (U_{-m}, U_m). Note that (T_{-m}, T_m) is not a possibility, because by assumption the fund managers would have received the same signal with certainty. Therefore, $\hat{\theta}^{**}_m(S^{-m}_{B_0}, S^m_{G_0}, \omega_{G_1})$ represents the probability of (U_{-m}, T_m) conditioning on the event $(S^{-m}_{B_0}, S^m_{G_0}, \omega_{G_1})$. The combination (U_{-m}, T_m) occurs with probability $\theta(1-\theta)$. Given (U_{-m}, T_m), $(S^{-m}_{B_0}, S^m_{G_0})$ is observed in state ω_{G_1} with probability $\frac{1}{2}p$. This reasoning explains the numerator and the first term of the denominator in (A.3.14). The rest of the denominator follows similarly for the (T_{-m}, U_m) and (U_{-m}, U_m) case. By symmetry,

$$
\begin{aligned}
\hat{\theta}^{**}_m(S^{-m}_{B_0}, S^m_{G_0}, \omega_{G_1}) &= \hat{\theta}^{**}_m(S^{-m}_{G_0}, S^m_{B_0}, \omega_{B_1}) \\
&= \frac{2\theta p}{1+\theta}. \qquad \text{(A.3.15)}
\end{aligned}
$$

The remaining updating rules are:

$$\begin{aligned}
\hat{\theta}^{**}_m(S^{-m}_{B_0}, S^m_{G_0}, \omega_{B_1}) &= \hat{\theta}^{**}_m(S^{-m}_{G_0}, S^m_{B_0}, \omega_{G_1}) \\
&= \frac{\frac{1}{2}(1-p)\theta(1-\theta)}{\frac{1}{2}p\theta(1-\theta) + \frac{1}{2}(1-p)\theta(1-\theta) + \frac{1}{4}(1-\theta)^2} \\
&= \frac{2\theta(1-p)}{1+\theta}, \qquad \text{(A.3.16)} \\
\hat{\theta}^{**}_m(S^{-m}_{B_0}, S^m_{B_0}, \omega_{G_1}) &= \hat{\theta}^{**}_m(S^{-m}_{G_0}, S^m_{G_0}, \omega_{B_1}) \\
&= \frac{(1-p)\theta^2 + \frac{1}{2}(1-p)\theta(1-\theta)}{(1-p)\theta^2 + (1-p)\theta(1-\theta) + \frac{1}{4}(1-\theta)^2} \\
&= \frac{2\theta(1-p)(1+\theta)}{4\theta(1-p) + (1-\theta)^2}, \qquad \text{(A.3.17)} \\
\hat{\theta}^{**}_m(S^{-m}_{B_0}, S^m_{B_0}, \omega_{B_1}) &= \hat{\theta}^{**}_m(S^{-m}_{G_0}, S^m_{G_0}, \omega_{G_1}) \\
&= \frac{p\theta^2 + \frac{1}{2}p\theta(1-\theta)}{p\theta^2 + p\theta(1-\theta) + \frac{1}{4}(1-\theta)^2} \\
&= \frac{2\theta p(1+\theta)}{4\theta p + (1-\theta)^2}. \qquad \text{(A.3.18)}
\end{aligned}$$

A.3.3 Calculations Involving Both Private Signals, but No Realized State of the World

This section shows calculations for the posterior probabilities of being the talented type and conditional state probabilities involving only both private signals in the information set.

Without conditioning on the realized state, both fund managers earn the same updated probability of being talented when their private signals in the first period are the equal. Similarly, both fund managers earn the same updated probability of being talented when their private signals in the first period are not equal. Denote $\hat{\theta}^{\dagger}_j$, $j = E, D$, as the posterior probability that a fund manager is talented when the private signals are equal and when private signals are different respectively:

$$
\begin{aligned}
\hat{\theta}^{\dagger}_{E} &\equiv \hat{\theta}^{\dagger}_{1}(S^1_{G_0}, S^2_{G_0}) = \hat{\theta}^{\dagger}_{2}(S^1_{G_0}, S^2_{G_0}) = \hat{\theta}^{\dagger}_{1}(S^1_{B_0}, S^2_{B_0}) = \hat{\theta}^{\dagger}_{2}(S^1_{B_0}, S^2_{B_0}) \\
&= \frac{\frac{1}{4}p\theta(1-\theta) + \frac{1}{4}(1-p)\theta(1-\theta) + \frac{1}{2}p\theta^2 + \frac{1}{2}(1-p)\theta^2}{\frac{1}{2}p\theta(1-\theta) + \frac{1}{2}(1-p)\theta(1-\theta) + \frac{1}{4}(1-\theta)^2 + \frac{1}{2}p\theta^2 + \frac{1}{2}(1-p)\theta^2} \\
&= \frac{\theta(1+\theta)}{1+\theta^2} > \theta, \qquad \text{(A.3.19)} \\
\hat{\theta}^{\dagger}_{D} &\equiv \hat{\theta}^{\dagger}_{1}(S^1_{B_0}, S^2_{G_0}) = \hat{\theta}^{\dagger}_{2}(S^1_{B_0}, S^2_{G_0}) = \hat{\theta}^{\dagger}_{1}(S^1_{G_0}, S^2_{B_0}) = \hat{\theta}^{\dagger}_{2}(S^1_{G_0}, S^2_{B_0}) \\
&= \frac{\frac{1}{4}p\theta(1-\theta) + \frac{1}{4}(1-p)\theta(1-\theta)}{\frac{1}{2}p\theta(1-\theta) + \frac{1}{2}(1-p)\theta(1-\theta) + \frac{1}{4}(1-\theta)^2} \\
&= \frac{\theta}{1+\theta} < \theta. \qquad \text{(A.3.20)}
\end{aligned}
$$

Using $\hat{\theta}^{\dagger}_{E}$ and $\hat{\theta}^{\dagger}_{D}$, we can calculate conditional probabilities:

$$
\begin{aligned}
\mathbb{P}(\omega_{G_2}|S^1_{B_1}, S^2_{G_1}, \hat{\theta}^{\dagger}_{j}) &= \mathbb{P}(\omega_{G_2}|S^1_{G_1}, S^2_{B_1}, \hat{\theta}^{\dagger}_{j}) \\
&= 1 - \mathbb{P}(\omega_{B_2}|S^1_{B_1}, S^2_{G_1}, \hat{\theta}^{\dagger}_{j}) = 1 - \mathbb{P}(\omega_{B_2}|S^1_{G_1}, S^2_{B_1}, \hat{\theta}^{\dagger}_{j}) \\
&= \frac{\frac{1}{2}[\frac{1}{2}p\hat{\theta}^{\dagger}_{j}(1-\hat{\theta}^{\dagger}_{j}) + \frac{1}{2}(1-p)\hat{\theta}^{\dagger}_{j}(1-\hat{\theta}^{\dagger}_{j}) + \frac{1}{4}(1-\hat{\theta}^{\dagger}_{j})^2]}{\frac{1}{2}[p\hat{\theta}^{\dagger}_{j}(1-\hat{\theta}^{\dagger}_{j}) + (1-p)\hat{\theta}^{\dagger}_{j}(1-\hat{\theta}^{\dagger}_{j}) + \frac{1}{2}(1-\hat{\theta}^{\dagger}_{j})^2]} \\
&= \frac{1}{2}, \quad j = E, D, \qquad \text{(A.3.21)} \\
\mathbb{P}(\omega_{G_2}|S^1_{B_1}, S^2_{B_1}, \hat{\theta}^{\dagger}_{j}) &= \mathbb{P}(\omega_{B_2}|S^1_{G_1}, S^2_{G_1}, \hat{\theta}^{\dagger}_{j}) \\
&= 1 - \mathbb{P}(\omega_{B_2}|S^1_{B_1}, S^2_{B_1}, \hat{\theta}^{\dagger}_{j}) = 1 - \mathbb{P}(\omega_{G_2}|S^1_{G_1}, S^2_{G_1}, \hat{\theta}^{\dagger}_{j}) \\
&= \frac{4\hat{\theta}^{\dagger}_{j}(1-p) + (1-\hat{\theta}^{\dagger}_{j})^2}{4\hat{\theta}^{\dagger}_{j} + 2(1-\hat{\theta}^{\dagger}_{j})^2}, \quad j = E, D, \qquad \text{(A.3.22)} \\
\Rightarrow \mathbb{P}(\omega_{B_2}|S^1_{B_1}, S^2_{B_1}, \hat{\theta}^{\dagger}_{j}) &= \mathbb{P}(\omega_{G_2}|S^1_{G_1}, S^2_{G_1}, \hat{\theta}^{\dagger}_{j}) \\
&= \frac{4\hat{\theta}^{\dagger}_{j}p + (1-\hat{\theta}^{\dagger}_{j})^2}{4\hat{\theta}^{\dagger}_{j} + 2(1-\hat{\theta}^{\dagger}_{j})^2}, \quad j = E, D. \qquad \text{(A.3.23)}
\end{aligned}
$$

$$
\begin{aligned}
\mathbb{P}(\omega_{G_2}|S_{G_1},\hat{\theta}_j^\dagger) &= 1-\mathbb{P}(\omega_{B_2}|S_{G_1},\hat{\theta}_j^\dagger) \\
&= \frac{[\hat{\theta}_j^\dagger p+(1-\hat{\theta}_j^\dagger)\frac{1}{2}]}{\frac{1}{2}}\cdot\frac{1}{2} \\
&= \frac{1}{2}+\hat{\theta}_j^\dagger(p-\frac{1}{2}), \quad j=E,D, \qquad \text{(A.3.24)} \\
\Rightarrow \mathbb{P}(\omega_{B_2}|S_{G_1},\hat{\theta}_j^\dagger) &= \frac{1}{2}-\hat{\theta}_j^\dagger(p-\frac{1}{2}), \quad j=E,D, \qquad \text{(A.3.25)} \\
\mathbb{P}(\omega_{G_2}|S_{B_1},\hat{\theta}_j^\dagger) &= 1-\mathbb{P}(\omega_{B_2}|S_{B_1},\hat{\theta}_j^\dagger) \\
&= \frac{[\hat{\theta}_j^\dagger(1-p)+(1-\hat{\theta}_j^\dagger)\frac{1}{2}]}{\frac{1}{2}}\cdot\frac{1}{2} \\
&= \frac{1}{2}+\hat{\theta}_j^\dagger(\frac{1}{2}-p), \quad j=E,D, \qquad \text{(A.3.26)} \\
\Rightarrow \mathbb{P}(\omega_{B_2}|S_{B_1},\hat{\theta}_j^\dagger) &= \frac{1}{2}-\hat{\theta}_j^\dagger(\frac{1}{2}-p), \quad j=E,D. \qquad \text{(A.3.27)}
\end{aligned}
$$

It is also helpful to calculate the probabilities for certain private signal combinations in the second period when conditioning on $\hat{\theta}_j^\dagger$, $j=E,D$:

$$
\begin{aligned}
\mathbb{P}(S^1_{G_1},S^2_{G_1}|\hat{\theta}_j^\dagger) &= \mathbb{P}(S^1_{B_1},S^2_{B_1}|\hat{\theta}_j^\dagger) \\
&= \frac{1}{2}p\hat{\theta}_j^{\dagger 2}+\frac{1}{2}(1-p)\hat{\theta}_j^{\dagger 2}+\frac{1}{2}p\hat{\theta}_j^\dagger(1-\hat{\theta}_j^\dagger) \\
&\quad +\frac{1}{2}(1-p)\hat{\theta}_j^\dagger(1-\hat{\theta}_j^\dagger)+\frac{1}{4}(1-\hat{\theta}_j^\dagger)^2 \\
&= \frac{1}{4}(1+\hat{\theta}_j^{\dagger 2}), \quad j=E,D, \qquad \text{(A.3.28)} \\
\mathbb{P}(S^1_{B_1},S^2_{G_1}|\hat{\theta}_j^\dagger) &= \mathbb{P}(S^1_{G_1},S^2_{B_1}|\hat{\theta}_j^\dagger) \\
&= \frac{1}{2}p\hat{\theta}_j^\dagger(1-\hat{\theta}_j^\dagger)+\frac{1}{2}(1-p)\hat{\theta}_j^\dagger(1-\hat{\theta}_j^\dagger)+\frac{1}{4}(1-\hat{\theta}_j^\dagger)^2 \\
&= \frac{1}{4}(1-\hat{\theta}_j^{\dagger 2}), \quad j=E,D. \qquad \text{(A.3.29)}
\end{aligned}
$$

$\mathbb{E}_0[X^2(2)|S^1(0),S^2(0)]$ can be rewritten as $\mathbb{E}_0[X^2(2)|\hat{\theta}_j^\dagger]$. There is an equal probability that Fund Manager 2 will be the first fund manager to invest in the second period or the second fund manager in the second period to invest. Refer to the chosen fund manager to move first as Fund Manager l. As mentioned in Section 1.2.3, regardless of $\hat{\theta}_1$ and $\hat{\theta}_2$, Fund Manager 2 maximizes $\mathbb{E}_1[X^2(2)|S^1(1), S^2(1), \hat{\theta}_1, \hat{\theta}_2, l = 2]$ by choosing:

- $C^2(1) =$ Investment R_1^2 when $S^1(1) = S^1_{G_1}$,
- $C^2(1) =$ Investment S_1^2 when $S^1(1) = S^1_{B_1}$.

Fund Manager 2 maximizes $\mathbb{E}_1[X^2(2)|S^1(1), S^2(1), \hat{\theta}_1, \hat{\theta}_2, l = 1]$ by choosing:

- $C^2(1) =$ Investment R_1^2 when $(S^1_{G_1}, S^2_{G_1})$,
- $C^2(1) =$ Investment R_1^2 when $(S^1_{B_1}, S^2_{G_1})$,
- $C^2(1) =$ Investment R_1^2 when $(S^1_{G_1}, S^2_{B_1})$,
- $C^2(1) =$ Investment S_1^2 when $(S^1_{B_1}, S^2_{B_1})$.

$$
\begin{aligned}
\mathbb{E}_0[X^2(2)|\hat{\theta}_j^\dagger, l=1] = \quad & r_G \cdot \mathbb{P}(\omega_{G_2}|S^1_{G_1}, S^2_{G_1}, \hat{\theta}_j^\dagger) \cdot \mathbb{P}(S^1_{G_1}, S^2_{G_1}|\hat{\theta}_j^\dagger) \\
+ \quad & r_B \cdot \mathbb{P}(\omega_{B_2}|S^1_{G_1}, S^2_{G_1}, \hat{\theta}_j^\dagger) \cdot \mathbb{P}(S^1_{G_1}, S^2_{G_1}|\hat{\theta}_j^\dagger) \\
+ \quad & r_G \cdot \mathbb{P}(\omega_{G_2}|S^1_{G_1}, S^2_{B_1}, \hat{\theta}_j^\dagger) \cdot \mathbb{P}(S^1_{G_1}, S^2_{B_1}|\hat{\theta}_j^\dagger) \\
+ \quad & r_B \cdot \mathbb{P}(\omega_{B_2}|S^1_{G_1}, S^2_{B_1}, \hat{\theta}_j^\dagger) \cdot \mathbb{P}(S^1_{G_1}, S^2_{B_1}|\hat{\theta}_j^\dagger) \\
+ \quad & r_G \cdot \mathbb{P}(\omega_{G_2}|S^1_{B_1}, S^2_{G_1}, \hat{\theta}_j^\dagger) \cdot \mathbb{P}(S^1_{B_1}, S^2_{G_1}|\hat{\theta}_j^\dagger) \\
+ \quad & r_B \cdot \mathbb{P}(\omega_{B_2}|S^1_{B_1}, S^2_{G_1}, \hat{\theta}_j^\dagger) \cdot \mathbb{P}(S^1_{B_1}, S^2_{G_1}|\hat{\theta}_j^\dagger) \\
+ \quad & r \cdot \mathbb{P}(S^1_{B_1}, S^2_{B_1}|\hat{\theta}_j^\dagger) \\
= \quad & r_G \cdot \frac{4\hat{\theta}_j^\dagger p + (1-\hat{\theta}_j^\dagger)^2}{4\hat{\theta}_j^\dagger + 2(1-\hat{\theta}_j^\dagger)^2} \cdot \frac{1}{4}(1+\hat{\theta}_j^{\dagger 2}) \\
+ \quad & r_B \cdot \frac{4\hat{\theta}_j^\dagger (1-p) + (1-\hat{\theta}_j^\dagger)^2}{4\hat{\theta}_j^\dagger + 2(1-\hat{\theta}_j^\dagger)^2} \cdot \frac{1}{4}(1+\hat{\theta}_j^{\dagger 2}) \\
+ \quad & r_G \cdot \frac{1}{2} \cdot \frac{1}{4}(1-\hat{\theta}_j^{\dagger 2}) \\
+ \quad & r_B \cdot \frac{1}{2} \cdot \frac{1}{4}(1-\hat{\theta}_j^{\dagger 2}) \\
+ \quad & r_G \cdot \frac{1}{2} \cdot \frac{1}{4}(1-\hat{\theta}_j^{\dagger 2}) \\
+ \quad & r_B \cdot \frac{1}{2} \cdot \frac{1}{4}(1-\hat{\theta}_j^{\dagger 2}) \\
+ \quad & r \cdot \frac{1}{4}(1+\hat{\theta}_j^{\dagger 2}) \\
= \quad & \frac{1}{8} r_G \big[3 + 4\hat{\theta}_j^\dagger (p - \frac{1}{2}) - \hat{\theta}_j^{\dagger 2}\big] \\
+ \quad & \frac{1}{8} r_B \big[3 - 4\hat{\theta}_j^\dagger (p - \frac{1}{2}) - \hat{\theta}_j^{\dagger 2}\big] \\
+ \quad & \frac{1}{4} r (1+\hat{\theta}_j^{\dagger 2}), \quad j = E, D. \qquad \text{(A.3.30)}
\end{aligned}
$$

$$
\begin{aligned}
\mathbb{E}_0[X^2(2)|\hat{\theta}_j^\dagger, l=2] = & \quad r_G \cdot \mathbb{P}(\omega_{G_2}|S_{G_1}, \hat{\theta}_j^\dagger) \cdot \mathbb{P}(S_{G_1}|\hat{\theta}_j^\dagger) \\
& + \quad r_B \cdot \mathbb{P}(\omega_{B_2}|S_{G_1}, \hat{\theta}_j^\dagger) \cdot \mathbb{P}(S_{G_1}|\hat{\theta}_j^\dagger) \\
& + \quad r \cdot \mathbb{P}(S_{B_1}|\hat{\theta}_j^\dagger) \\
= & \quad \frac{1}{8} r_G \big[2 + 4\hat{\theta}_j^\dagger(p - \frac{1}{2})\big] \\
& + \quad \frac{1}{8} r_B \big[2 - 4\hat{\theta}_j^\dagger(p - \frac{1}{2})\big] \\
& + \quad \frac{1}{2} r, \quad j = E, D.
\end{aligned} \tag{A.3.31}
$$

$$
\begin{aligned}
\mathbb{E}_0[X^2(2)|\hat{\theta}_j^\dagger] \quad = & \quad \frac{1}{2}\mathbb{E}_0[X^2(2)|\hat{\theta}_j^\dagger, l=1] + \frac{1}{2}\mathbb{E}_0[X^2(2)|\hat{\theta}_j^\dagger, l=2] \\
= & \quad \frac{1}{16} r_G \big[5 + 8\hat{\theta}_j^\dagger(p - \frac{1}{2}) - \hat{\theta}_j^{\dagger 2}\big] \\
+ & \quad \frac{1}{16} r_B \big[5 - 8\hat{\theta}_j^\dagger(p - \frac{1}{2}) - \hat{\theta}_j^{\dagger 2}\big] \\
+ & \quad \frac{1}{8} r(3 + \hat{\theta}_j^{\dagger 2}), \quad j = E, D.
\end{aligned} \tag{A.3.32}
$$

A.3.4 Calculations Involving One Private Signal, but No Realized State of the World

This section calculates $\mathbb{E}_0[X^l(2)|S^1(0)]$, which is the expected return in the second period by Fund Manager 1 who can only condition on the signal she received in the first period. As shown in 1.2.13, a fund manager does not learn anything about her type when conditioning only on her private signal. Therefore, $\mathbb{E}_0[X^l(2)|S^1(0)] = \mathbb{E}_0[X^l(2)|\theta]$. The calculation is the same that is summarized in A.3.32, and we can simply replace $\hat{\theta}_j^\dagger$ with θ:

$$
\begin{aligned}
\mathbb{E}_0[X^2(2)|\theta] &= \frac{1}{2}\mathbb{E}_0[X^2(2)|\theta, l=1] + \frac{1}{2}\mathbb{E}_0[X^2(2)|\theta, l=2] \\
&= \frac{1}{16} r_G \big[5 + 8\theta(p - \frac{1}{2}) - \theta^2\big] \\
&+ \frac{1}{16} r_B \big[5 - 8\theta(p - \frac{1}{2}) - \theta^2\big] \\
&+ \frac{1}{8} r(3 + \theta^2). \qquad \text{(A.3.33)}
\end{aligned}
$$

Appendix B

B.1 Descriptive Statistics

Metropolitan Area	2000Q4	2005Q4	2010Q4
New York City	267	481	505
San Francisco	87	120	133
Boston	89	122	151
Chicago	73	108	126
Los Angeles	61	83	91
Philadelphia	46	71	70
Baltimore/Washington DC	40	55	59
London	13	34	62
Dallas/Fort Worth	17	37	42
Minneapolis	22	28	34
Toronto	5	21	41
Houston	22	32	30
Milwaukee	28	32	42
Atlanta	22	30	38
Richmond	18	21	33
Total	810	1,275	1,457

Table B.1: Institution Count By Metropolitan Area

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	539	743	867
Hedge Fund Company	132	356	409
Bank Management Division	66	82	77
Mutual Fund Manager	44	62	76
Insurance Management Division	29	32	28
Total	810	1,275	1,457

Table B.2: Institution Count By Institution Type

Metropolitan Area	2000Q4	2005Q4	2010Q4
New York City	260	472	498
San Francisco	85	117	130
Boston	83	115	144
Chicago	72	106	125
Los Angeles	60	81	88
Philadelphia	45	70	69
Baltimore/Washington DC	39	54	58
London	13	34	61
Dallas/Fort Worth	17	37	42
Minneapolis	22	28	34
Toronto	5	21	40
Houston	22	32	30
Milwaukee	28	32	42
Atlanta	21	29	37
Richmond	18	21	33
Total	790	1,249	1,431

Table B.3: Institution Count By Metropolitan Area (Exclude Over $50 Billion Equity)

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	534	735	856
Hedge Fund Company	132	356	409
Bank Management Division	61	76	73
Mutual Fund Manager	34	50	65
Insurance Management Division	29	32	28
Total	790	1,249	1,431

Table B.4: Institution Count By Institution Type (Exclude Over $50 Billion Equity)

Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	Total
New York City	335	622	21	20	15	1,013
San Francisco	119	84	7	12	0	222
Boston	143	58	9	8	2	220
Chicago	119	37	16	2	5	179
Los Angeles	106	40	6	5	3	160
Philadelphia	87	17	15	3	1	123
Baltimore/Washington DC	72	11	9	8	0	100
London	43	30	7	8	7	95
Dallas/Fort Worth	29	34	5	2	1	71
Minneapolis	41	16	3	1	1	62
Toronto	26	5	5	15	3	54
Houston	39	8	5	0	0	52
Milwaukee	37	3	6	4	2	52
Atlanta	45	4	1	0	1	51
Richmond	41	5	2	0	0	48
Total	1,282	974	117	88	41	2,502

Table B.5: Institution Count By Metropolitan Area And Institution Type (Exclude Over $50 Billion Equity)

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	1,691	2,412	2,166
Hedge Fund Company	490	1,015	1,061
Bank Management Division	3,713	4,390	5,303
Mutual Fund Manager	5,507	8,154	7,832
Insurance Management Division	3,781	4,089	7,038
All	1,888	2,407	2,363

Table B.6: Mean Market Cap ($ Millions) By Institution Type (Exclude Over $50 Billion Equity)

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	141	205	200
Hedge Fund Company	65	112	108
Bank Management Division	442	607	579
Mutual Fund Manager	581	692	572
Insurance Management Division	323	407	573
All	183	233	221

Table B.7: Mean Number of Equity Holdings By Institution Type

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	131	190	184
Hedge Fund Company	65	112	108
Bank Management Division	324	444	471
Mutual Fund Manager	300	348	322
Insurance Management Division	323	407	573
All	149	195	190

Table B.8: Mean Number of Equity Holdings By Institution Type (Exclude Over $50 Billion Equity)

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	7.12	6.14	6.31
Hedge Fund Company	17.62	13.55	13.02
Bank Management Division	5.52	4.23	5.69
Mutual Fund Manager	6.94	6.19	5.70
Insurance Management Division	6.38	5.32	5.59
All	8.72	8.12	8.15

Table B.9: Mean Quarterly Turnover Rate By Institution Type (Exclude Over $50 Billion Equity)

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	3.43	2.83	3.24
Hedge Fund Company	13.47	10.58	9.82
Bank Management Division	1.33	1.97	1.55
Mutual Fund Manager	2.41	2.65	2.20
Insurance Management Division	3.45	1.63	1.80
All	4.83	4.94	4.91

Table B.10: Mean Quarterly Turnover Rate By Institution Type (*Major Portfolio Changes*)

Institution Type	2000Q4	2005Q4	2010Q4
Investment Adviser	3.46	2.86	3.28
Hedge Fund Company	13.47	10.58	9.82
Bank Management Division	1.43	2.12	1.64
Mutual Fund Manager	2.88	3.25	2.54
Insurance Management Division	3.45	1.63	1.80
All	4.95	5.04	5.00

Table B.11: Mean Quarterly Turnover Rate By Institution Type (Exclude Over $50 Billion Equity; *Major Portfolio Changes*)

B.2 Results by Network

Institution Type	LSV Herding Statistic	LSV Herding Statistic (*Major Portfolio Changes*)
Investment Adviser	1.752**	3.969**
Buy	2.282**	4.434**
Sell	1.102**	4.323**
(Stock-Quarters)	(114,704)	(72,389)
Hedge Fund Company	2.416**	3.307**
Buy	2.529**	3.662**
Sell	2.303**	3.276**
(Stock-Quarters)	(75,575)	(50,650)
Bank Management Division	1.397**	7.122**
Buy	2.029**	3.837**
Sell	0.699**	3.593**
(Stock-Quarters)	(89,703)	(3,418)
Mutual Fund Manager	1.292**	7.493**
Buy	1.613**	4.803**
Sell	0.935**	5.225**
(Stock-Quarters)	(90,851)	(2,795)
Insurance Management Division	1.394**	17.144**
Buy	2.313**	10.840**
Sell	0.436**	13.904**
(Stock-Quarters)	(28,211)	(174)
All	1.668**	3.887**
Buy	2.119**	3.995**
Sell	1.165**	3.781**
(Stock-Quarters)	(399,044)	(129,426)

Table B.12: Mean LSV Herding Statistics By 5 *Type* Networks: † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Institution Type	LSV Herding Statistic	LSV Herding Statistic (*Major Portfolio Changes*)
Investment Adviser	1.666**	3.938**
Buy	2.294**	3.939**
Sell	0.907**	3.938**
(Stock-Quarters)	(110,109)	(68,915)
Hedge Fund Company	2.410**	2.297**
Buy	2.521**	3.487**
Sell	2.299**	3.115**
(Stock-Quarters)	(75,286)	(50,530)
Bank Management Division	1.142**	6.074**
Buy	1.779**	5.323**
Sell	0.475**	6.795**
(Stock-Quarters)	(65,111)	(2,718)
Mutual Fund Manager	0.514**	6.005**
Buy	0.529**	6.951**
Sell	0.498**	5.684**
(Stock-Quarters)	(50,312)	(1,277)
Insurance Management Division	1.397**	17.144**
Buy	2.321**	14.146**
Sell	0.433**	24.782**
(Stock-Quarters)	(28,209)	(174)
All	1.533**	3.763**
Buy	1.982**	3.832**
Sell	1.048**	3.700**
(Stock-Quarters)	(329,027)	(123,614)

Table B.13: Mean LSV Herding Statistics By 5 *Type* Networks (Exclude Over $50 Billion Equity): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Metropolitan Area	LSV Herding Statistic	LSV Herding Statistic (*Major Portfolio Changes*)
New York City	1.455**	2.691**
Buy	2.030**	2.998**
Sell	0.811**	2.399**
(Stock-Quarters)	(105,972)	(62,977)
San Francisco	0.914**	4.389**
Buy	1.290**	4.438**
Sell	0.512**	4.342**
(Stock-Quarters)	(59,738)	(3,555)
Boston	1.322**	4.155**
Buy	1.998**	4.559**
Sell	0.571**	3.887**
(Stock-Quarters)	(84,636)	(12,387)
Chicago	0.685**	3.063**
Buy	1.018**	3.219**
Sell	0.319**	2.912**
(Stock-Quarters)	(60,155)	(7,006)
Los Angeles	0.439**	3.939**
Buy	0.642**	3.734**
Sell	0.230**	4.132**
(Stock-Quarters)	(27,199)	(1,094)

Table B.14: Mean LSV Herding Statistics By 15 *Metro* Networks (1 of 3): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Metropolitan Area	LSV Herding Statistic	LSV Herding Statistic (*Major Portfolio Changes*)
Philadelphia	0.524**	3.879**
Buy	0.830**	5.275**
Sell	0.167**	2.715**
(Stock-Quarters)	(44,242)	(1,550)
Baltimore/Washington DC	0.481**	10.679**
Buy	0.654**	11.817**
Sell	0.307**	10.747**
(Stock-Quarters)	(16,051)	(123)
London	0.265**	4.945**
Buy	0.525**	5.624**
Sell	0.003	4.455**
(Stock-Quarters)	(24,666)	(553)
Dallas/Fort Worth	0.719**	1.686
Buy	0.451**	7.926**
Sell	1.002**	-0.163
(Stock-Quarters)	(8,344)	(112)
Minneapolis	0.279**	3.511
Buy	-0.006	8.567†
Sell	0.579**	1.792
(Stock-Quarters)	(10,307)	(40)

Table B.15: Mean LSV Herding Statistics By 15 *Metro* Networks (2 of 3): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Metropolitan Area	LSV Herding Statistic	LSV Herding Statistic (*Major Portfolio Changes*)
Toronto	1.059**	7.492**
Buy	0.76**	6.881*
Sell	1.373**	11.626**
(Stock-Quarters)	(8,366)	(54)
Houston	0.332**	2.758†
Buy	0.710**	2.938
Sell	-0.039	5.152
(Stock-Quarters)	(6,159)	(48)
Milwaukee	1.042**	7.171**
Buy	1.163**	11.960**
Sell	0.917**	7.828**
(Stock-Quarters)	(14,958)	(69)
Atlanta	0.653**	0.861
Buy	0.408**	1.702
Sell	0.907**	1.308
(Stock-Quarters)	(7,488)	(26)
Richmond	0.904**	3.585
Buy	1.379**	15.022
Sell	0.464*	5.018
(Stock-Quarters)	(3,868)	(18)
All	0.944**	3.056**
Buy	1.335**	3.375**
Sell	0.519**	2.777**
(Stock-Quarters)	(482,149)	(89,632)

Table B.16: Mean LSV Herding Statistics By 15 *Metro* Networks (3 of 3): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Metropolitan Area	LSV Herding Statistic	LSV Herding Statistic (*Major Portfolio Changes*)
New York City	1.302**	2.508**
Buy	1.859**	2.744**
Sell	0.683**	2.282**
(Stock-Quarters)	(97,500)	(59,520)
San Francisco	0.906**	3.907**
Buy	1.044**	4.044**
Sell	0.762**	3.775**
(Stock-Quarters)	(40,952)	(3,368)
Boston	1.159**	3.723**
Buy	1.514**	4.102**
Sell	0.765**	3.362**
(Stock-Quarters)	(59,459)	(9,912)
Chicago	0.624**	2.888**
Buy	0.749**	3.141**
Sell	0.490**	2.798**
(Stock-Quarters)	(50,835)	(6,818)
Los Angeles	0.401**	3.682**
Buy	0.523**	3.405**
Sell	0.273**	3.946**
(Stock-Quarters)	(25,355)	(994)

Table B.17: Mean LSV Herding Statistics By 15 *Metro* Networks (Exclude Over $50 Billion Equity) (1 of 3): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Metropolitan Area	LSV Herding Statistic	LSV Herding Statistic (*Major Portfolio Changes*)
Philadelphia	0.726**	3.441**
Buy	0.879**	4.732**
Sell	0.559**	2.343**
(Stock-Quarters)	(36,288)	(1,526)
Baltimore/Washington DC	0.586**	9.342**
Buy	0.537**	10.381**
Sell	0.635**	9.554**
(Stock-Quarters)	(12,594)	(108)
London	0.250**	4.837**
Buy	0.524**	5.241**
Sell	-0.027	4.570**
(Stock-Quarters)	(24,483)	(550)
Dallas/Fort Worth	0.757**	1.654
Buy	0.521**	7.923**
Sell	1.005**	-0.218
(Stock-Quarters)	(8,266)	(112)
Minneapolis	0.279**	3.511
Buy	-0.006	8.567†
Sell	0.579**	1.792
(Stock-Quarters)	(10,307)	(40)

Table B.18: Mean LSV Herding Statistics By 15 *Metro* Networks (Exclude Over $50 Billion Equity) (2 of 3): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Metropolitan Area	LSV Herding Statistic	LSV Herding Statistic (*Major Portfolio Changes*)
Toronto	1.026**	7.875**
Buy	0.666**	7.555**
Sell	1.408**	11.408*
(Stock-Quarters)	(7,942)	(52)
Houston	0.332**	2.758†
Buy	0.710**	2.938
Sell	-0.039	5.152
(Stock-Quarters)	(6,159)	(48)
Milwaukee	1.042**	7.171**
Buy	1.163**	11.960**
Sell	0.917**	7.828**
(Stock-Quarters)	(14,958)	(69)
Atlanta	0.665**	-0.728
Buy	0.653**	-0.925
Sell	0.676**	-1.705
(Stock-Quarters)	(5,782)	(24)
Richmond	0.904**	3.585
Buy	1.379**	15.022
Sell	0.464*	5.018
(Stock-Quarters)	(3,868)	(18)
All	0.882**	2.802**
Buy	1.137**	3.074**
Sell	0.609**	2.564**
(Stock-Quarters)	(404,748)	(83,159)

Table B.19: Mean LSV Herding Statistics By 15 *Metro* Networks (Exclude Over $50 Billion Equity) (3 of 3): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
New York City	1.101**	2.792**	0.245**	0.226**	-1.486**	1.275**
Buy	1.652**	2.953**	0.017	-0.141†	-1.358**	1.479**
Sell	0.483**	2.638**	0.483**	0.640**	-1.611**	1.064**
(Stock-Quarters)	(77,754)	(57,467)	(22,567)	(21,834)	(9,982)	(189,604)
San Francisco	0.609**	0.099	0.327**	-3.087	-	0.476**
Buy	0.579**	0.044	0.600**	-0.442	-	0.552**
Sell	0.640**	0.261	0.062	-3.455**	-	0.412**
(Stock-Quarters)	(12,286)	(1,193)	(6,626)	(56)	(0)	(20,161)
Boston	1.013**	-0.058	1.181**	0.980	-	0.777**
Buy	1.578**	-0.293	2.006**	-0.154	-	1.144**
Sell	0.394**	0.319	0.430	0.359**	-	0.385**
(Stock-Quarters)	(53,658)	(927)	(1,630)	(18,418)	(0)	(74,633)
Chicago	0.874**	0.513**	0.546**	-	-	0.822**
Buy	0.838**	-0.088	1.341**	-	-	0.798**
Sell	0.913**	1.189**	-0.188	-	-	0.850**
(Stock-Quarters)	(36,868)	(3,409)	(3,120)	(0)	(0)	(43,397)

Table B.20: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (1 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
	Investment	Hedge Fund	Bank Management	Mutual Fund	Insurance	
Metropolitan Area	Adviser	Company	Division	Manager	Division	All
Los Angeles	0.383**	-5.834**	-1.357	-	-	0.367**
Buy	0.527**	3.306	-0.870	-	-	0.523**
Sell	0.233**	-6.880**	-1.810*	-	-	0.213*
(Stock-Quarters)	(19,328)	(25)	(83)	(0)	(0)	(19,436)
Philadelphia	0.697**	-10.565**	0.839**	-	-	0.735**
Buy	0.722**	-6.498	1.318**	-	-	0.885**
Sell	0.671**	-11.921*	0.386*	-	-	0.583**
(Stock-Quarters)	(13,410)	(4)	(5,329)	(0)	(0)	(18,743)
Baltimore/Washington DC	0.832**	-	0.069	-2.199†	-	0.780**
Buy	0.841**	-	-0.342	0.731	-	0.787**
Sell	0.823**	-	0.501	-2.832†	-	0.787**
(Stock-Quarters)	(7,123)	(0)	(328)	(45)	(0)	(7,496)
London	0.158	-0.820	-1.451**	-	-2.188**	-0.008
Buy	-0.054	1.041	-0.933	-	-1.869*	-0.140
Sell	0.374*	-2.101†	-1.931*	-	-2.408**	0.133
(Stock-Quarters)	(6,820)	(117)	(262)	(0)	(303)	(7,502)

Table B.21: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (2 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Dallas/Fort Worth	0.169	-0.024	-	-	-	0.161
Buy	-0.420	1.433	-	-	-	-0.348
Sell	0.798**	-0.670	-	-	-	0.728*
(Stock-Quarters)	(2,108)	(97)	(0)	(0)	(0)	(2,205)
Minneapolis	0.249*	-	-	-	-	0.249*
Buy	0.089	-	-	-	-	0.089
Sell	0.461*	-	-	-	-	0.461*
(Stock-Quarters)	(5,306)	(0)	(0)	(0)	(0)	(5,306)
Toronto	0.153	-	-	0.543	-	0.350
Buy	0.439	-	-	1.258*	-	0.848*
Sell	-0.077	-	-	0.169	-	0.461
(Stock-Quarters)	(623)	(0)	(0)	(638)	(0)	(1,261)
Houston	0.030	-	-	-	-	0.030
Buy	-0.116	-	-	-	-	0.848
Sell	0.183	-	-	-	-	0.048
(Stock-Quarters)	(4,289)	(0)	(0)	(0)	(0)	(4,289)

Table B.22: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (3 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Milwaukee	0.931**	-	-	-	-	0.931**
Buy	1.122**	-	-	-	-	1.122**
Sell	0.735**	-	-	-	-	0.735**
(Stock-Quarters)	(5,733)	(0)	(0)	(0)	(0)	(5,733)
Atlanta	0.633**	-	-	-	-	0.633**
Buy	0.667**	-	-	-	-	0.667**
Sell	0.600**	-	-	-	-	0.600**
(Stock-Quarters)	(6,277)	(0)	(0)	(0)	(0)	(6,277)
Richmond	0.911**	-	-	-	-	0.911**
Buy	1.196**	-	-	-	-	1.196**
Sell	0.640**	-	-	-	-	0.640**
(Stock-Quarters)	(3,486)	(0)	(0)	(0)	(0)	(3,486)
All	0.854**	2.563**	0.384**	0.166**	-1.506**	0.944**
Buy	1.148**	2.673**	0.447**	-0.126†	-1.373**	1.121**
Sell	0.539**	2.465**	0.321**	0.495**	-1.635**	0.763**
(Stock-Quarters)	(255,069)	(63,239)	(39,945)	(40,991)	(10,285)	(409,529)

Table B.23: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (4 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
New York City	0.884**	2.792**	-0.001	-0.133	-1.486**	1.367**
Buy	1.498**	2.958**	-0.101	-.346†	-1.358**	1.703**
Sell	0.214**	2.630**	0.240†	0.087	-1.611**	1.030**
(Stock-Quarters)	(70,032)	(57,041)	(8,996)	(4,439)	(9,982)	(150,490)
San Francisco	0.673**	0.099	-0.135	-14.880**	-	0.490**
Buy	0.809**	0.044	-0.861**	-	-	0.462**
Sell	0.535**	0.261	0.908**	-	-	0.568**
(Stock-Quarters)	(11,921)	(1,193)	(2,641)	(4)	(0)	(15,759)
Boston	1.179**	-0.058	1.918**	-0.367	-	1.172**
Buy	1.766**	-0.293	3.159**	0.738	-	1.757**
Sell	0.544**	0.319	0.830*	-0.303	-	0.546**
(Stock-Quarters)	(45,814)	(927)	(1,199)	(56)	(0)	(47,996)
Chicago	0.916**	0.513**	0.137	-	-	0.839**
Buy	0.754**	-0.088	0.691*	-	-	0.679**
Sell	1.091**	1.189**	-0.378	-	-	1.013**
(Stock-Quarters)	(34,452)	(3,409)	(2,178)	(0)	(0)	(40,039)

Table B.24: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (Exclude Over $50 Billion Equity) (1 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Los Angeles	0.356**	-5.834**	-1.357	-	-	0.339**
Buy	0.553**	3.306	-0.870	-	-	0.594**
Sell	0.152†	-6.880**	-1.810*	-	-	0.130
(Stock-Quarters)	(17,276)	(25)	(83)	(0)	(0)	(17,384)
Philadelphia	0.697**	-10.565**	0.839**	-	-	0.735**
Buy	0.722	-6.498	1.318	-	-	0.885**
Sell	0.671	-11.921	0.386	-	-	0.583**
(Stock-Quarters)	(13,410)	(4)	(5,329)	(0)	(0)	(18,743)
Baltimore/Washington DC	0.796**	-	0.069	-12.898**	-	0.760**
Buy	0.853	-	-0.342	-	-	0.796**
Sell	0.742	-	0.501	-	-	0.724**
(Stock-Quarters)	(6,902)	(0)	(328)	(2)	(0)	(7,232)
London	0.128	-0.820	-1.451**	-	-2.188**	-0.040
Buy	-0.096	1.041	-0.933	-	-1.869	-0.180
Sell	0.356	-2.101	-1.931	-	-2.408	0.110
(Stock-Quarters)	(6,618)	(117)	(262)	(0)	(303)	(7,300)

Table B.25: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (Exclude Over $50 Billion Equity) (2 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Dallas/Fort Worth	0.175	-0.024	-	-	-	0.166
Buy	-0.385	1.433	-	-	-	-0.313
Sell	0.772	-0.670	-	-	-	0.702*
(Stock-Quarters)	(2,072)	(97)	(0)	(0)	(0)	(2,169)
Minneapolis	0.249*	-	-	-	-	0.249*
Buy	0.089	-	-	-	-	0.089
Sell	0.461	-	-	-	-	0.461*
(Stock-Quarters)	(5,306)	(0)	(0)	(0)	(0)	(5,306)
Toronto	0.125	-	-	0.543	-	0.357
Buy	0.729	-	-	1.258	-	1.022*
Sell	-0.380	-	-	0.169	-	-0.076
(Stock-Quarters)	(510)	(0)	(0)	(638)	(0)	(1,148)
Houston	0.030	-	-	-	-	0.030
Buy	-0.116	-	-	-	-	-0.116
Sell	0.183	-	-	-	-	0.183
(Stock-Quarters)	(4,289)	(0)	(0)	(0)	(0)	(4,289)

Table B.26: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (Exclude Over $50 Billion Equity) (3 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Milwaukee	0.931**	-	-	-	-	0.931**
Buy	1.122	-	-	-	-	1.122**
Sell	0.735	-	-	-	-	0.735**
(Stock-Quarters)	(5,733)	(0)	(0)	(0)	(0)	(5,733)
Atlanta	0.607**	-	-	-	-	0.607**
Buy	0.571	-	-	-	-	0.571**
Sell	0.643	-	-	-	-	0.643**
(Stock-Quarters)	(4,798)	(0)	(0)	(0)	(0)	(4,798)
Richmond	0.911**	-	-	-	-	0.911**
Buy	1.196	-	-	-	-	1.196**
Sell	0.640	-	-	-	-	0.640**
(Stock-Quarters)	(3,486)	(0)	(0)	(0)	(0)	(3,486)
All	0.820**	2.560**	0.296**	-0.068	-1.506**	1.030**
Buy	1.118**	2.674**	0.388**	-0.146	-1.373**	1.265**
Sell	0.504**	2.457**	0.294**	0.064	-1.635**	0.796**
(Stock-Quarters)	(232,619)	(62,813)	(21,016)	(5,139)	(10,285)	(331,872)

Table B.27: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (Exclude Over $50 Billion Equity) (4 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
New York City	2.844**	3.635**	17.385**	15.965**	9.504**	3.430**
Buy	3.049**	3.820**	17.490**	21.922**	16.604*	3.618**
Sell	2.780**	3.460**	40.902**	33.764**	23.796*	3.298**
(Stock-Quarters)	(12,867)	(30,600)	(46)	(39)	(23)	(43,575)
San Francisco	4.722**	-1.126	9.230*	-	-	3.823**
Buy	5.175**	0.606	18.216*	-	-	4.633**
Sell	4.491**	-1.459	46.634*	-	-	3.717**
(Stock-Quarters)	(409)	(94)	(18)	(0)	(0)	(521)
Boston	5.553**	-7.328**	0.000	4.796*	-	5.491**
Buy	6.216**	-4.684†	-	33.358**	-	6.216**
Sell	4.949**	-8.690**	-	36.18**	-	4.919**
(Stock-Quarters)	(3,807)	(16)	(2)	(29)	(0)	(3,854)
Chicago	7.402**	2.221	0.000	-	-	7.048**
Buy	7.544**	3.006	-	-	-	7.279**
Sell	7.395**	2.023	-	-	-	7.076**
(Stock-Quarters)	(1,025)	(65)	(7)	(0)	(0)	(1,097)

Table B.28: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (*Major Portfolio Changes*) (1 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Los Angeles	5.887**	-14.632	-	-	-	6.826**
Buy	8.308**	-	-	-	-	8.308**
Sell	5.796**	-	-	-	-	5.689**
(Stock-Quarters)	(350)	(1)	(0)	(0)	(0)	(351)
Philadelphia	4.424**	-	0.000	-	-	4.303**
Buy	5.465**	-	-	-	-	5.465**
Sell	3.976**	-	-	-	-	3.976**
(Stock-Quarters)	(355)	(0)	(10)	(0)	(0)	(365)
Baltimore/Washington DC	8.341**	-	-	-	-	8.341**
Buy	13.172**	-	-	-	-	13.172**
Sell	8.714*	-	-	-	-	8.714*
(Stock-Quarters)	(49)	(0)	(0)	(0)	(0)	(49)
London	-0.797	-14.632	-	-	-	-1.720†
Buy	-	-	-	-	-	-11.163
Sell	-	-	-	-	-	-14.632
(Stock-Quarters)	(14)	(1)	(0)	(0)	(0)	(15)

Table B.29: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (*Major Portfolio Changes*) (2 of 4):
† Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Dallas/Fort Worth	0.000	-14.632	-	-	-	-2.439
Buy	-	-	-	-	-	-
Sell	-	-	-	-	-	-
(Stock-Quarters)	(5)	(1)	(0)	(0)	(0)	(6)
Minneapolis	1.968	-	-	-	-	1.968
Buy	11.238	-	-	-	-	11.238
Sell	0.776	-	-	-	-	0.776
(Stock-Quarters)	(13)	(0)	(0)	(0)	(0)	(13)
Toronto	-	-	-	-	-	-
Buy	-	-	-	-	-	-
Sell	-	-	-	-	-	-
(Stock-Quarters)	(0)	(0)	(0)	(0)	(0)	(0)
Houston	2.110	-	-	-	-	2.110
Buy	13.330*					13.330*
Sell	1.070					1.070
(Stock-Quarters)	(22)	(0)	(0)	(0)	(0)	(22)

Table B.30: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (*Major Portfolio Changes*) (3 of 4):
† Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Milwaukee	4.929†	-	-	-	-	4.929†
Buy	18.229†					18.229†
Sell	3.946					3.946
(Stock-Quarters)	(22)	(0)	(0)	(0)	(0)	(22)
Atlanta	-1.691	-	-	-	-	-1.691
Buy	2.634					2.634
Sell	6.430					6.430
(Stock-Quarters)	(17)	(0)	(0)	(0)	(0)	(17)
Richmond	7.249†	-	-	-	-	7.249†
Buy	23.218					23.218
Sell	10.609					10.609
(Stock-Quarters)	(14)	(0)	(0)	(0)	(0)	(14)
All	3.789**	3.610**	11.637**	11.201**	9.504**	3.705**
Buy	3.615**	3.807**	17.611**	23.447**	16.604*	3.960**
Sell	4.133**	3.432**	41.784**	34.167**	23.796*	3.539**
(Stock-Quarters)	(18,969)	(30,778)	(83)	(68)	(23)	(49,921)

Table B.31: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (*Major Portfolio Changes*) (4 of 4):
† Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
New York City	2.753**	3.643**	5.294†	6.022	9.504**	3.394**
Buy	2.632**	3.805**	28.469	28.469	16.604*	3.469**
Sell	2.876**	3.489**	40.357	12.862	23.796*	3.326**
(Stock-Quarters)	(12,119)	(30,408)	(13)	(9)	(23)	(42,572)
San Francisco	4.623**	-1.126	0.000	-	-	3.483**
Buy	4.871**	0.606	-	-	-	4.126**
Sell	4.902**	-1.459	-	-	-	3.646**
(Stock-Quarters)	(389)	(94)	(3)	(0)	(0)	(486)
Boston	5.355**	-7.328**	0.000	-	-	5.277**
Buy	6.131**	-4.684†	-	-	-	6.100**
Sell	4.613**	-8.690**	-	-	-	4.550**
(Stock-Quarters)	(3,641)	(16)	(2)	(0)	(0)	(3,659)
Chicago	7.239**	2.221	0.000	-	-	6.900**
Buy	7.333**	3.006	-	-	-	7.074**
Sell	7.281**	2.023	-	-	-	6.960**
(Stock-Quarters)	(998)	(65)	(5)	(0)	(0)	(1,068)

Table B.32: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (Exclude Over $50 Billion Equity; *Major Portfolio Changes*) (1 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Los Angeles	5.871**	-14.632	-	-	-	5.802**
Buy	7.563**	-	-	-	-	7.563**
Sell	4.708**	-	-	-	-	4.590**
(Stock-Quarters)	(300)	(1)	(0)	(0)	(0)	(301)
Philadelphia	4.424**	-	0.000	-	-	4.303**
Buy	5.465**	-	-	-	-	5.465**
Sell	3.976**	-	-	-	-	3.976**
(Stock-Quarters)	(355)	(0)	(10)	(0)	(0)	(365)
Baltimore/Washington DC	6.699**	-	-	-	-	6.699**
Buy	13.456**	-	-	-	-	13.456**
Sell	6.154†	-	-	-	-	6.154†
(Stock-Quarters)	(46)	(0)	(0)	(0)	(0)	(46)
London	-0.797	-14.632	-	-	-	-1.720†
Buy	-	-	-	-	-	-11.163
Sell	-	-	-	-	-	-14.632
(Stock-Quarters)	(14)	(1)	(0)	(0)	(0)	(15)

Table B.33: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (Exclude Over $50 Billion Equity; *Major Portfolio Changes*) (2 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Dallas/Fort Worth	0.000	-14.632	-	-	-	-2.439
Buy	-	-	-	-	-	-
Sell	-	-	-	-	-	-
(Stock-Quarters)	(5)	(1)	(0)	(0)	(0)	(6)
Minneapolis	1.968	-	-	-	-	1.968
Buy	11.238	-	-	-	-	11.238
Sell	0.776	-	-	-	-	0.776
(Stock-Quarters)	(13)	(0)	(0)	(0)	(0)	(13)
Toronto	-	-	-	-	-	-
Buy	-	-	-	-	-	-
Sell	-	-	-	-	-	-
(Stock-Quarters)	(0)	(0)	(0)	(0)	(0)	(0)
Houston	2.110	-	-	-	-	2.110
Buy	13.330*					13.330*
Sell	1.070					1.070
(Stock-Quarters)	(22)	(0)	(0)	(0)	(0)	(22)

Table B.34: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (Exclude Over $50 Billion Equity; *Major Portfolio Changes*) (3 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

	Institution Type					
Metropolitan Area	Investment Adviser	Hedge Fund Company	Bank Management Division	Mutual Fund Manager	Insurance Division	All
Milwaukee	4.929†	-	-	-	-	4.929†
Buy	18.229†					18.229†
Sell	3.946					3.946
(Stock-Quarters)	(22)	(0)	(0)	(0)	(0)	(22)
Atlanta	-2.162	-	-	-	-	-2.162
Buy	2.957					2.957
Sell	5.343					5.343
(Stock-Quarters)	(14)	(0)	(0)	(0)	(0)	(14)
Richmond	7.249†	-	-	-	-	7.249†
Buy	23.218					23.218
Sell	10.609					10.609
(Stock-Quarters)	(14)	(0)	(0)	(0)	(0)	(14)
All	3.659**	3.618**	2.086†	6.022	9.504**	3.635**
Buy	3.789**	3.791**	28.469	28.469	16.604*	3.796**
Sell	3.600**	3.461**	40.357	12.862	23.796*	3.518**
(Stock-Quarters)	(17,952)	(30,586)	(33)	(9)	(23)	(48,603)

Table B.35: Mean LSV Herding Statistics By 75 *TypeMetro* Networks (Exclude Over $50 Billion Equity; *Major Portfolio Changes*) (4 of 4): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

B.3 Results by Market Capitalization and VIX Quintiles

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	1.551**	3.155**	2.742**	2.444**	6.150**	3.105**
Buy	0.557	2.706*	0.120	-2.222†	-0.699	0.376
Sell	2.379**	3.533**	4.619**	5.470**	9.447**	5.034**
(Stock-Quarters)	(392)	(271)	(350)	(183)	(277)	(1,473)
2	1.688**	2.886**	2.150**	0.707**	3.177**	2.189**
Buy	1.427**	2.602**	2.269**	0.237	3.018**	1.986**
Sell	1.950**	3.131**	2.036**	1.177**	3.330**	2.382**
(Stock-Quarters)	(5,375)	(4,042)	(4,257)	(2,187)	(3,321)	(19,182)
3	1.674**	2.066**	1.575**	0.994**	1.799**	1.684**
Buy	2.729**	3.565**	2.633**	1.714**	2.716**	2.776**
Sell	0.007	-0.048	0.180†	-0.026	0.518**	0.117*
(Stock-Quarters)	(18,219)	(14,568)	(12,732)	(7,643)	(11,209)	(64,371)
4	1.660**	1.520**	1.454**	1.159**	1.531**	1.494**
Buy	2.385**	2.564**	2.267**	1.938**	2.177**	2.298**
Sell	0.677**	0.127†	0.380**	0.061	0.671**	0.410**
(Stock-Quarters)	(29,253)	(24,471)	(21,151)	(16,059)	(20,627)	(111,561)
5 (largest)	2.134**	1.829**	1.659**	1.354**	1.346**	1.698**
Buy	2.200**	2.026**	1.841**	1.342**	1.263**	1.772**
Sell	2.072**	1.649**	1.488**	1.366**	1.425**	1.629**
(Stock-Quarters)	(47,793)	(43,827)	(38,952)	(32,055)	(39,830)	(202,457)
All	1.888**	1.835**	1.621**	1.232**	1.563**	1.668**
Buy	2.323**	2.506**	2.125**	1.532**	1.844**	2.119**
Sell	1.385**	1.104**	1.071**	0.899**	1.252**	1.165**
(Stock-Quarters)	(101,032)	(87,179)	(77,442)	(58,127)	(75,264)	(399,044)

Table B.36: 5 *Type* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles: † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	1.403*	2.705**	0.742	0.826	2.420**	1.593**
Buy	1.516†	3.747**	-1.154	-2.962*	-1.727†	0.207
Sell	1.305†	1.780†	2.111*	3.633**	5.037**	2.659**
(Stock-Quarters)	(279)	(187)	(248)	(141)	(199)	(1,054)
2	1.290**	2.111**	1.465**	0.936**	1.736**	1.536**
Buy	2.053**	2.620**	1.228**	0.534	1.192**	1.695**
Sell	0.435†	1.573**	1.674**	1.327**	2.251**	1.376**
(Stock-Quarters)	(3,566)	(2,511)	(2,615)	(1,351)	(2,137)	(12,180)
3	1.764**	1.741**	1.394**	0.962**	1.431**	1.523**
Buy	3.113**	2.766**	1.862**	1.476**	1.509**	2.302**
Sell	-0.157	0.457**	0.835**	0.330†	1.342**	0.543**
(Stock-Quarters)	(10,429)	(8,255)	(7,772)	(4,720)	(7,328)	(38,504)
4	1.685**	1.430**	1.343**	1.097**	1.142**	1.428**
Buy	2.623**	2.185**	1.791**	1.863**	1.744**	2.090**
Sell	0.560**	0.447**	0.814**	0.131	1.017**	0.617**
(Stock-Quarters)	(21,905)	(19,053)	(16,732)	(12,009)	(16,711)	(86,410)
5 (largest)	2.023**	1.696**	1.549**	1.205**	1.273**	1.583**
Buy	2.835**	2.048**	1.928**	1.444**	1.419**	1.883**
Sell	1.664**	1.349**	1.161**	0.969**	1.124**	1.283**
(Stock-Quarters)	(44,688)	(41,383)	(37,001)	(29,940)	(37,867)	(190,879)
All	1.863**	1.647**	1.470**	1.146**	1.346**	1.533**
Buy	2.540**	2.200**	1.847**	1.525**	1.504**	1.982**
Sell	1.121**	1.043**	1.065**	0.739**	1.177**	1.048**
(Stock-Quarters)	(80,867)	(71,389)	(64,368)	(48,161)	(64,242)	(329,027)

Table B.37: 5 *Type* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles (Exclude Over $50 Billion Equity): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	11.955**	13.181**	12.430**	20.784**	12.757**	13.334**
Buy	10.331†	15.050**	9.252*	-5.885	6.207	9.001**
Sell	12.806**	11.992*	14.902**	25.229**	14.758**	15.338**
(Stock-Quarters)	(32)	(18)	(32)	(14)	(47)	(143)
2	4.435**	7.677**	7.854**	7.455**	6.698**	6.578**
Buy	3.651**	4.666**	6.814**	4.021*	8.102**	5.564**
Sell	4.961**	9.397**	8.612**	9.669**	5.409**	7.285**
(Stock-Quarters)	(844)	(685)	(641)	(199)	(539)	(2,908)
3	3.829**	4.934**	4.746**	5.044**	5.041**	4.567**
Buy	4.818**	4.877**	5.231**	5.233**	6.473**	5.235**
Sell	2.803**	4.990**	4.229**	4.871**	3.379**	3.876**
(Stock-Quarters)	(4,705)	(3,261)	(2,952)	(1,291)	(2,377)	(14,586)
4	3.687**	3.819**	4.222**	4.072**	3.959**	3.910**
Buy	4.195**	3.718**	4.297**	4.406**	4.422**	4.173**
Sell	3.195**	3.921**	4.151**	3.760**	3.485**	3.654**
(Stock-Quarters)	(10,657)	(7,678)	(6,873)	(3,944)	(6,118)	(35,270)
5 (largest)	3.536**	3.682**	3.742**	3.569**	3.608**	3.627**
Buy	3.695**	3.637**	3.700**	3.742**	3.322**	3.619**
Sell	3.378**	3.730**	3.786**	3.397**	3.884**	3.636**
(Stock-Quarters)	(19,412)	(16,450)	(15,205)	(10,639)	(14,813)	(76,519)
All	3.649**	3.969**	4.099**	3.874**	3.928**	3.887**
Buy	4.263**	4.231**	3.792**	4.210**	4.111**	3.995**
Sell	3.655**	3.860**	4.469**	3.734**	3.882**	3.781**
(Stock-Quarters)	(35,650)	(28,092)	(25,703)	(16,087)	(23,894)	(129,426)

Table B.38: 5 *Type* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles (*Major Portfolio Changes*): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	10.089**	13.251**	10.226**	17.332**	10.975**	11,613**
Buy	14.972*	14.789*	4.110	-5.792	0.380	6.723*
Sell	6.709†	12.397*	14.930**	21.957**	14.393**	13.929**
(Stock-Quarters)	(22)	(14)	(23)	(12)	(41)	(112)
2	3.712**	6.210**	7.153**	6.633**	5.687**	5.639**
Buy	3.645**	3.740**	6.224**	3.605*	5.902**	4.722**
Sell	3.758**	7.815**	7.760**	8.642**	5.479**	6.289**
(Stock-Quarters)	(701)	(561)	(552)	(173)	(464)	(2,451)
3	3.472**	4.615**	4.264**	4.873**	4.685**	4.211**
Buy	4.448**	4.424**	4.249**	4.755**	5.676**	4.649**
Sell	2.489**	4.794**	4.280**	4.976**	3.499**	3.768**
(Stock-Quarters)	(4,255)	(2,894)	(2,669)	(1,202)	(2,195)	(13,215)
4	3.556**	3.639**	4.031**	4.155**	3.980**	3.808**
Buy	4.095**	3.474**	3.963**	4.492**	4.162**	3.989**
Sell	3.039**	3.805**	4.096**	3.847**	3.796**	3.633**
(Stock-Quarters)	(10,033)	(7,183)	(6,504)	(3,738)	(5,841)	(33,299)
5 (largest)	3.522**	3.649**	3.669**	3.553**	3.559**	3.590**
Buy	3.654**	3.698**	3.538**	3.777**	3.313**	3.592**
Sell	3.389**	3.601**	3.809**	3.331**	3.840**	3.597**
(Stock-Quarters)	(18,887)	(16,003)	(14,766)	(10,394)	(14,487)	(74,537)
All	3.534**	3.810**	3.915**	3.845**	3.829**	3.763**
Buy	3.889**	3.719**	3.773**	4.013**	3.824**	3.832**
Sell	3.184**	3.903**	4.059**	3.685**	3.862**	3.700**
(Stock-Quarters)	(33,898)	(26,655)	(24,514)	(15,519)	(23,028)	(123,614)

Table B.39: 5 *Type* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles (Exclude Over $50 Billion Equity; *Major Portfolio Changes*): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	2.133*	0.055	1.980*	2.026	5.785**	2.294**
Buy	1.169	0.414	0.787	0.752	-0.452	0.638
Sell	2.818*	-0.328	3.619**	3.059	8.762**	3.741**
(Stock-Quarters)	(195)	(153)	(197)	(67)	(130)	(742)
2	1.228**	2.327**	1.626**	1.061**	2.031**	1.674**
Buy	1.302**	1.980**	1.626**	0.194	1.956**	1.522**
Sell	1.167**	2.666**	1.626**	1.895**	2.106**	1.820**
(Stock-Quarters)	(3,144)	(2,411)	(2,615)	(1,229)	(1,968)	(11,367)
3	1.557**	1.576**	1.310**	0.866**	1.235**	1.373**
Buy	3.162**	2.876**	2.243**	1.495**	2.254**	2.568**
Sell	-0.779**	-0.413**	0.023	0.097	-0.235†	1.955**
(Stock-Quarters)	(13,246)	(9,979)	(9,524)	(5,351)	(8,381)	(46,481)
4	1.076**	1.027**	0.959**	0.887**	0.853**	0.974**
Buy	2.206**	2.128**	1.803**	1.794**	1.687**	1.955**
Sell	-0.457**	-0.488**	-0.157*	-0.319**	-0.281**	-0.351**
(Stock-Quarters)	(27,705)	(22,115)	(20,971)	(14,468)	(20,012)	(105,271)
5 (largest)	0.941**	0.882**	0.860**	0.769**	0.717**	0.842**
Buy	1.023**	0.894**	0.930**	0.896**	0.621**	0.877**
Sell	0.863**	0.871**	0.791**	0.645**	0.812**	0.807**
(Stock-Quarters)	(76,041)	(66,656)	(62,952)	(49,121)	(63,518)	(318,288)
All	1.050**	1.015**	0.949**	0.807**	0.827**	0.944**
Buy	1.600**	1.442**	1.300**	1.138**	1.062**	1.335**
Sell	0.454**	0.548**	0.566**	0.456**	0.570**	0.519**
(Stock-Quarters)	(120,331)	(101,314)	(96,259)	(70,236)	(94,009)	(482,149)

Table B.40: 15 *Metro* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles: † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	0.264	0.440	0.391	1.852	2.695*	1.019*
Buy	0.790	0.171	-0.832	-1.026	-2.025	-0.421
Sell	-0.174	0.729	1.234	5.253†	5.292**	2.169**
(Stock-Quarters)	(110)	(83)	(103)	(48)	(93)	(437)
2	1.014**	1.394**	0.859**	1.815**	0.942**	1.127**
Buy	1.510**	2.072**	0.722*	2.382**	0.361	1.363**
Sell	0.476	0.609†	1.001**	1.221*	1.422**	0.884**
(Stock-Quarters)	(1,811)	(1,261)	(1,394)	(653)	(1,115)	(6,234)
3	1.446**	1.274**	1.070**	1.239**	0.755**	1.173**
Buy	2.394**	2.489**	1.802**	1.900**	0.891**	1.959**
Sell	0.282	-0.237*	0.256	0.612*	0.143**	0.136†
(Stock-Quarters)	(7,336)	(5,733)	(5,601)	(3,302)	(5,360)	(27,332)
4	1.049**	1.010**	0.936**	1.128**	0.823**	0.984**
Buy	0.879**	0.941**	0.967**	0.954**	0.816**	1.608**
Sell	0.850**	0.866*	0.661*	0.603**	0.648	0.189**
(Stock-Quarters)	(19,779)	(15,888)	(15,580)	(10,547)	(15,581)	(77,375)
5 (largest)	0.864**	0.904**	0.815**	0.778**	0.732**	0.823**
Buy	1.024**	0.975**	0.858**	0.870**	0.885**	0.908**
Sell	0.679**	0.738**	0.717**	0.585**	0.579**	0.737**
(Stock-Quarters)	(69,697)	(60,886)	(58,368)	(45,155)	(59,264)	(293,370)
All	0.947**	0.956**	0.856**	0.878**	0.756**	0.882**
Buy	1.180**	1.288**	1.133**	1.137**	0.929**	1.137**
Sell	0.688**	0.597**	0.564**	0.609**	0.575**	0.609**
(Stock-Quarters)	(98,733)	(83,851)	(81,046)	(59,705)	(81,413)	(404,748)

Table B.41: 15 *Metro* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles (Exclude Over $50 Billion Equity): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	10.165**	9.294**	8.950*	23.978**	10.661**	11.093**
Buy	5.402	4.967	4.278	19.186	3.638	5.427*
Sell	13.908*	12.659**	15.623*	25.575**	12.482**	14.420**
(Stock-Quarters)	(25)	(16)	(17)	(8)	(34)	(100)
2	5.246**	4.276**	7.334**	5.560**	6.187**	5.613**
Buy	3.431**	0.997	8.036**	4.156*	4.696**	4.031**
Sell	6.081**	6.172**	6.953**	6.963**	7.163**	6.506**
(Stock-Quarters)	(536)	(423)	(344)	(106)	(306)	(1,715)
3	3.997**	4.556**	3.792**	4.029**	4.464**	4.166**
Buy	5.007**	5.255**	5.642**	3.848**	5.896**	5.248**
Sell	2.982**	3.766**	1.936**	4.249**	2.790**	3.005**
(Stock-Quarters)	(2,766)	(2,004)	(1,666)	(593)	(1,301)	(8,330)
4	3.230**	3.577**	3.515**	3.551**	2.829**	3.326**
Buy	3.772**	4.094**	4.536**	3.925**	3.606**	3.974**
Sell	2.727**	3.051**	2.607**	3.167**	2.076**	2.709**
(Stock-Quarters)	(6,379)	(4,470)	(3,953)	(2,097)	(3,463)	(20,362)
5 (largest)	2.690**	2.530**	2.875**	2.971**	2.613**	2.718**
Buy	3.035**	2.562**	2.995**	3.516**	2.389**	2.866**
Sell	2.368**	2.518**	2.771**	2.491**	2.922**	2.612**
(Stock-Quarters)	(14,599)	(12,216)	(12,084)	(8,255)	(11,971)	(59,125)
All	3.044**	3.031**	3.190**	3.178**	2.878**	3.056**
Buy	3.465**	3.213**	3.649**	3.629**	2.977**	3.375**
Sell	2.654**	2.870**	2.769**	2.764**	2.868**	2.777**
(Stock-Quarters)	(24,305)	(19,129)	(18,064)	(11,059)	(17,075)	(89,632)

Table B.42: 15 *Metro* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles (*Major Portfolio Changes*): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	5.756	11.464**	4.701	30.708**	10.577*	9.748**
Buy	7.611	10.705*	2.405	35.061	-1.089	5.710*
Sell	3.901	12.224*	6.997	29.258**	18.744**	13.155**
(Stock-Quarters)	(12)	(12)	(14)	(4)	(17)	(59)
2	3.245**	2.329**	6.253**	4.940**	4.424**	3.977**
Buy	2.011*	-0.519	4.465**	7.183*	1.978†	2.180**
Sell	3.959**	4.243**	7.218**	2.885†	6.122**	5.105**
(Stock-Quarters)	(371)	(316)	(274)	(69)	(227)	(1,257)
3	3.239**	3.434**	2.798**	3.584**	3.416**	3.251**
Buy	3.993**	4.247**	3.095**	3.281**	4.413**	3.897**
Sell	2.514**	2.572**	2.505**	3.955**	2.312**	2.586**
(Stock-Quarters)	(2,326)	(1,665)	(1,384)	(489)	(1,146)	(7,010)
4	2.981**	3.367**	3.205**	3.231**	2.606**	3.069**
Buy	3.519**	3.969**	3.507**	3.478**	3.406**	3.593**
Sell	2.514**	2.766**	2.926**	2.986**	1.785**	2.573**
(Stock-Quarters)	(5,750)	(4,051)	(3,568)	(1,806)	(3,201)	(18,376)
5 (largest)	2.654**	2.465**	2.688**	2.876**	2.524**	2.626**
Buy	2.980**	2.776**	2.794**	3.239**	2.360**	2.810**
Sell	2.411**	2.198**	2.593**	2.555**	2.683**	2.479**
(Stock-Quarters)	(13,873)	(11,666)	(11,545)	(7,823)	(11,550)	(56,457)
All	2.811**	2.766**	2.867**	2.998**	2.639**	2.802**
Buy	3.214**	3.160**	2.987**	3.317**	2.725**	3.074**
Sell	2.481**	2.407**	2.758**	2.707**	2.562**	2.564**
(Stock-Quarters)	(22,332)	(17,710)	(16,785)	(10,191)	(16,141)	(83,159)

Table B.43: 15 *Metro* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles (Exclude Over $50 Billion Equity; *Major Portfolio Changes*): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	1.873	0.848	1.966	6.577	1.704	1.943*
Buy	1.916	-0.974	1.409	6.307	-1.059	0.954
Sell	1.829	3.091	2.621	6.913	3.595	2.946*
(Stock-Quarters)	(44)	(29)	(37)	(9)	(32)	(151)
2	1.561**	1.555**	1.873**	3.125**	1.640**	1.743**
Buy	2.336**	1.688**	0.500	2.287*	1.121†	1.563**
Sell	0.831*	1.429**	3.402**	3.964**	2.190**	1.924**
(Stock-Quarters)	(1,187)	(799)	(801)	(232)	(568)	(3,587)
3	1.595**	1.832**	1.585**	1.456**	1.317**	1.587**
Buy	3.021**	3.056**	1.855**	1.939**	1.554**	2.450**
Sell	-0.411*	0.292	1.217**	0.290**	1.010**	0.453**
(Stock-Quarters)	(7,111)	(5,124)	(4,763)	(2,019)	(3,813)	(22,830)
4	1.538**	1.421**	1.458**	1.032**	1.197**	1.375**
Buy	2.631**	2.303**	1.744**	1.536**	1.638**	2.070**
Sell	0.194*	0.284*	1.089**	0.414**	0.608**	0.490**
(Stock-Quarters)	(19,099)	(14,444)	(13,366)	(7,872)	(12,173)	(66,954)
5 (largest)	0.960**	0.869**	0.769**	0.605**	0.708**	0.796**
Buy	1.074**	0.836**	0.676**	0.556**	0.665**	0.779**
Sell	0.854**	0.907**	0.871**	0.659**	0.759**	0.819**
(Stock-Quarters)	(73,405)	(65,855)	(62,073)	(49,041)	(65,033)	(316,007)
All	1.122**	1.025**	0.941**	0.702**	0.816**	0.944**
Buy	1.567**	1.258**	0.942**	0.753**	0.875**	1.121**
Sell	0.665**	0.786**	0.946**	0.652**	0.761**	0.763**
(Stock-Quarters)	(100,846)	(86,251)	(81,640)	(59,173)	(81,619)	(409,529)

Table B.44: 75 *TypeMetro* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles: † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	0.010	0.399	1.644	5.271	1.861	1.272
Buy	0.911	1.345	3.317	4.922	-1.026	1.519
Sell	-0.844	-0.461	-0.416	5.707	3.946	1.036
(Stock-Quarters)	(37)	(27)	(29)	(9)	(31)	(127)
2	1.340**	1.375**	1.523**	3.723**	1.549**	1.577**
Buy	2.083**	2.321**	0.467	2.993*	1.414*	1.721**
Sell	0.564	0.441	2.610**	4.469**	1.692*	1.429**
(Stock-Quarters)	(948)	(588)	(623)	(182)	(452)	(2,793)
3	1.598**	1.696**	1.362**	1.507**	1.306**	1.510**
Buy	2.669**	2.627**	1.649**	1.700**	1.422**	2.156**
Sell	0.099	0.522*	1.029**	1.293**	1.167**	0.702**
(Stock-Quarters)	(5,332)	(3,804)	(3,586)	(1,568)	(3,118)	(17,408)
4	1.529**	1.460**	1.478**	1.270**	1.248**	1.421**
Buy	2.519**	2.245**	1.962**	1.660**	1.757**	2.109**
Sell	0.302**	0.472**	0.910**	0.794**	0.605**	0.574**
(Stock-Quarters)	(15,451)	(11,444)	(10,635)	(6,178)	(10,117)	(53,825)
5 (largest)	1.124**	0.968**	0.858**	0.723**	0.815**	0.910**
Buy	1.229**	1.033**	1.004**	0.735**	0.907**	0.997**
Sell	1.026**	0.907**	0.758**	0.716**	0.725**	0.836**
(Stock-Quarters)	(57,768)	(52,945)	(51,527)	(40,582)	(54,897)	(257,719)
All	1.237**	1.093**	0.991**	0.830**	0.906**	1.030**
Buy	1.620**	1.361**	1.201**	0.904**	1.072**	1.265**
Sell	0.838**	0.818**	0.812**	0.758**	0.735**	0.796**
(Stock-Quarters)	(79,536)	(68,802)	(66,400)	(48,519)	(68,615)	(331,872)

Table B.45: 75 *TypeMetro* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles (Exclude Over $50 Billion Equity): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	20.807*	6.262	7.415	18.398†	-13.798	10.594**
Buy	7.076	1.298	10.121	-	-	7.990†
Sell	34.538**	8.744	2.004	-	-13.798	12.619*
(Stock-Quarters)	(4)	(3)	(6)	(2)	(1)	(16)
2	5.875**	4.469**	8.797**	11.654†	7.446**	6.356**
Buy	5.772**	2.650	6.101*	9.462	7.903*	5.032**
Sell	5.945**	6.829**	10.556**	16.036†	7.147*	7.450**
(Stock-Quarters)	(147)	(108)	(76)	(9)	(38)	(378)
3	3.755**	5.029**	4.793**	5.340**	6.620**	4.656**
Buy	5.550**	4.963**	5.436**	4.741**	8.850**	5.665**
Sell	2.095**	5.101**	4.144**	6.489**	4.554**	3.635**
(Stock-Quarters)	(1,076)	(690)	(547)	(105)	(287)	(2,705)
4	4.383**	4.154**	4.351**	4.510**	4.884**	4.386**
Buy	5.578**	4.319**	5.042**	3.726**	6.390**	5.127**
Sell	3.335**	3.994**	3.688**	5.677**	3.406**	3.684**
(Stock-Quarters)	(3,356)	(2,187)	(1,695)	(498)	(1,036)	(8,772)
5 (largest)	3.602**	3.372**	3.238**	3.711**	3.394**	3.451**
Buy	4.067**	3.327**	3.315**	3.382**	3.412**	3.543**
Sell	3.385**	3.456**	3.195**	4.103**	3.431**	3.454**
(Stock-Quarters)	(10,268)	(8,549)	(7,788)	(4,497)	(6,948)	(38,050)
All	3.817**	3.630**	3.553**	3.842**	3.708**	3.705**
Buy	4.535**	3.618**	3.751**	3.471**	4.001**	3.960**
Sell	3.317**	3.677**	3.391**	4.294**	3.483**	3.539**
(Stock-Quarters)	(14,851)	(11,537)	(10,112)	(5,111)	(8,310)	(49,921)

Table B.46: 75 *TypeMetro* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles For (*Major Portfolio Changes*): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Market Cap	VIX Quintile					
Quintile	1 (lowest)	2	3	4	5 (highest)	All
1 (smallest)	15.401†	6.262	6.127	17.212†	-13.798	8.304*
Buy	6.894	1.298	6.127	-	-	5.715
Sell	32.416	8.744	-	17.212†	-13.798	11.755†
(Stock-Quarters)	(3)	(3)	(5)	(2)	(1)	(14)
2	5.342**	3.202*	5.847**	11.662†	7.008**	5.155**
Buy	6.300**	2.533	3.167	9.482	7.696*	4.671**
Sell	4.697**	4.205*	7.610**	16.021†	6.512†	5.578**
(Stock-Quarters)	(139)	(95)	(63)	(9)	(31)	(337)
3	3.531**	4.876**	4.648**	5.475**	6.219**	4.458**
Buy	5.345**	4.695**	4.903**	4.932**	8.145**	5.353**
Sell	1.854**	5.067**	4.415**	6.502**	4.530**	3.575**
(Stock-Quarters)	(1,022)	(630)	(503)	(1040)	(274)	(2,533)
4	4.412**	4.076**	4.464**	4.515**	4.743**	4.384**
Buy	5.515**	4.110**	5.198**	4.054**	6.226**	5.081**
Sell	3.385**	4.040**	3.761**	5.252**	3.298**	3.694**
(Stock-Quarters)	(3,219)	(2,080)	(1,601)	(480)	(1,001)	(8,381)
5 (largest)	3.501**	3.388**	3.162**	3.663**	3.341**	3.396**
Buy	3.714**	3.295**	3.173**	3.171**	3.382**	3.382**
Sell	3.358**	3.513**	3.175**	4.208**	3.353**	3.453**
(Stock-Quarters)	(9,984)	(8,397)	(7,650)	(4,431)	(6,876)	(37,338)
All	3.727**	3.599**	3.469**	3.802**	3.621**	3.635**
Buy	4.257**	3.527**	3.597**	3.329**	3.909**	3.796**
Sell	3.275**	3.697**	3.366**	4.351**	3.397**	3.518**
(Stock-Quarters)	(14,367)	(11,205)	(9,822)	(5,026)	(8,183)	(48,603)

Table B.47: 75 *TypeMetro* Networks Weighted Mean LSV Herding Statistics By Market Cap and VIX Quintiles For (Exclude Over $50 Billion Equity; *Major Portfolio Changes*): † Statistically significant at the 10% level, * Statistically significant at the 5% level, ** Statistically significant at the 1% level

Appendix C

C.1 Technicalities

C.1.1 Calculation of (3.2.20)

The infinitesimal generator, L, of a Markov process $\{X_t\}$ is defined by:

$$Lu(x) = \lim_{t \to +0} \frac{\mathbb{E}^x[u(X_t)] - u(x)}{t}. \tag{C.1.1}$$

Define the normalized value function as $\mathcal{W}(x;h) = rW(x;h)$. Write (3.2.19) in discrete bellman equation form and pass to the limit:

$$\mathcal{W}(x;h) = r\Delta t(-g(x)) + e^{-r\Delta t}\mathbb{E}^x[\mathcal{W}(X_{\Delta t};h)], \quad x < h, \tag{C.1.2}$$

$$\begin{aligned} \Rightarrow \quad & \mathcal{W}(x;h) - e^{-r\Delta t}\mathcal{W}(x;h) \\ = \quad & r\Delta t(-g(x)) + e^{-r\Delta t}\mathbb{E}^x[\mathcal{W}(X_{\Delta t};h) - \mathcal{W}(x;h)], \quad x < h. \end{aligned} \tag{C.1.3}$$

For small Δt, $e^{-r\Delta t} = 1 - r\Delta t + o(\Delta t)$.

$$\begin{aligned} \Rightarrow \quad & r\Delta t\mathcal{W}(x;h) + o(\Delta t) \\ = \quad & r\Delta t(-g(x)) + (1 - r\Delta t)\mathbb{E}^x[\mathcal{W}(X_{\Delta t};h) - \mathcal{W}(x;h)] + o(\Delta t), \\ & x < h. \end{aligned} \tag{C.1.4}$$

Divide (C.1.4) by Δt and let $\Delta t \to 0$:

$$\Rightarrow r\mathcal{W}(x;h) = r(-g(x)) + L\mathcal{W}(x;h), \quad x < h,$$

$$\Rightarrow (r-L)\mathcal{W}(x;h) = r(-g(x)), \quad x<h,$$

$$\Rightarrow (r-L)W(x;h) = -g(x), \quad x<h. \tag{C.1.5}$$

C.1.2 Calculation of (3.2.54)

The infinitesimal generator, L, of a Markov process $\{X_t\}$ is defined by:

$$Lu(x) = \lim_{t\to+0} \frac{\mathbb{E}^x[u(X_t)] - u(x)}{t}. \tag{C.1.6}$$

Denote the state specific infinitesimal generator as L_j, and the normalized value function as $v_j(x) = (r+\lambda_{jk})\mathrm{v}_j(x)$ for $j=1,2$, $j\neq k$. We can write (3.2.52) in discrete bellman equation form and pass to the limit.

$$\begin{aligned} v_j(x) &= (r+\lambda_{jk})\Delta t g_j(x) + (1-\lambda_{jk}\Delta t)e^{-(r+\lambda_{jk})\Delta t}\mathbb{E}^x[v_j(X^j_{\Delta t})] \\ &\quad +\lambda_{jk}\Delta t e^{-(r+\lambda_{jk})\Delta t}\mathbb{E}^x[v_k(X^j_{\Delta t})], \quad j=1,2, \quad j\neq k. \end{aligned} \tag{C.1.7}$$

Subtracting $(1-\lambda_{jk}\Delta t)e^{-(r+\lambda_{jk})\Delta t}v_j(x)$ from both sides of (C.1.7) yields:

$$\begin{aligned} & v_j(x) - (1-\lambda_{jk}\Delta t)e^{-(r+\lambda_{jk})\Delta t}v_j(x) \\ = \; & (r+\lambda_{jk})\Delta t g_j(x) + (1-\lambda_{jk}\Delta t)e^{-(r+\lambda_{jk})\Delta t}\mathbb{E}^x[v_j(X^j_{\Delta t}) - v_j(x)] \\ & +\lambda_{jk}\Delta t e^{-(r+\lambda_{jk})\Delta t}\mathbb{E}^x[v_k(X^j_{\Delta t})], \quad j=1,2, \quad j\neq k. \end{aligned} \tag{C.1.8}$$

For small Δt, $e^{-(r+\lambda_{jk})\Delta t} = 1-(r+\lambda_{jk})\Delta t + o(\Delta t)$. Therefore, (C.1.8) can be rewritten as:

$$\begin{aligned} & (r+\lambda_{jk})\Delta t v(x) + o(\Delta t) \\ = \; & (r+\lambda_{jk})\Delta t g_j(x) + (1-(r+\lambda_{jk})\Delta t)\mathbb{E}^x[v(X^j_{\Delta t}) - v(x)] \\ & +\lambda_{jk}\Delta t\mathbb{E}^x[v_k(X^j_{\Delta t})] + o(\Delta t), \quad j=1,2, \quad j\neq k. \end{aligned} \tag{C.1.9}$$

Dividing both sides of (C.1.9) by Δt and letting $\Delta t \to 0$ yields:

$$\begin{aligned}
(r+\lambda_{jk})v_j(x) &= (r+\lambda_j k)g(x) + L_j v_j(x) + \lambda_{jk}v_k(x), && \text{(C.1.10)}\\
\Rightarrow (r+\lambda_{jk}-L_j)v_j(x) &= (r+\lambda_{jk})g(x) + \lambda_{jk}v_k(x), && \text{(C.1.11)}\\
\Rightarrow (r+\lambda_{jk}-L_j)\mathrm{v}_j(x) &= g(x) + \lambda_{jk}\mathrm{v}_k(x), && \text{(C.1.12)}\\
& \quad j=1,2, \quad j \neq k.
\end{aligned}$$

C.1.3 Description of Grid Used to Calculate (3.2.63) and (3.2.64)

For some function $u(x)$ and characteristic equation root $\beta^+ > 0$, we define the expected present value operator on the supremum process as,

$$\mathcal{E}^+u(x) = \int_0^{+\infty} \beta^+ e^{-\beta^+ y} u(x+y)dy. \quad \text{(C.1.13)}$$

Create a grid for the spot value, x, of the price process. Denote x_k as the value of the spot process in the k^{th} position of the grid and define $\Delta = x_k - x_{k-1}$.

$$\mathcal{E}^+u(x_k) = \int_0^{+\infty} \beta^+ e^{-\beta^+ y} u(x_k+y)dy = e^{\beta^+ x_k}\int_{x_k}^{+\infty} \beta^+ e^{-\beta^+ y} u(y)dy. \quad \text{(C.1.14)}$$

Then,

$$\begin{aligned}
\mathcal{E}^+u(x_{k-1}) &= e^{\beta^+ x_{k-1}} \int_{x_{k-1}}^{+\infty} \beta^+ e^{-\beta^+ y} u(y)dy\\
&= e^{\beta^+ x_{k-1}} [\int_{x_k}^{+\infty} \beta^+ e^{-\beta^+ y} u(y)dy + \int_{x_{k-1}}^{x_k} \beta^+ e^{-\beta^+ y} u(y)dy]\\
&= e^{-\beta^+\Delta}\mathcal{E}^+u(x_k) + \int_{x_{k-1}}^{x_k} \beta^+ e^{\beta^+(x_{k-1}-y)} u(y)dy\\
&= e^{-\beta^+\Delta}\mathcal{E}^+u(x_k) + \int_0^{\Delta} \beta^+ e^{-\beta^+ y} u(x_{k-1}+y)dy. && \text{(C.1.15)}
\end{aligned}$$

$$\int_0^{\Delta} \beta^+ e^{-\beta^+ y} u(x_{k-1}+y)dy = \int_0^{\Delta} \beta^+ e^{-\beta^+ y}(u_{k-1} + y\frac{u_k - u_{k-1}}{\Delta})dy$$

$$= (1-e^{-\beta^+\Delta})u_{k-1} - e^{-\beta^+\Delta}(u_k - u_{k-1}) + \frac{1-e^{-\beta^+\Delta}}{\beta^+\Delta}(u_k - u_{k-1}), \quad \text{(C.1.16)}$$

where u_k denotes $u(x_k)$. Now,

$$\mathcal{E}^+ u(x_{k-1}) = e^{-\beta^+\Delta}\mathcal{E}^+ u(x_k) + \frac{1-e^{-\beta^+\Delta}(1+\beta^+\Delta)}{\beta^+\Delta}u_k - \frac{1-\beta^+\Delta - e^{-\beta^+\Delta}}{\beta^+\Delta}u_{k-1}. \quad \text{(C.1.17)}$$

(C.1.17) provides a recursive formula for calculating the expected present value operator on the supremum process. You can either estimate the last value in the grid, or set it to zero if the grid is large enough.

Using the characteristic root $\beta^- < 0$, a similar derivation provides the following recursive formula for the expected present value operator on the infimum process,

$$\mathcal{E}^- u(x_{k+1}) = e^{\beta^-\Delta}\mathcal{E}^- u(x_k) + \frac{1+\beta^-\Delta - e^{\beta^-\Delta}}{\beta^-\Delta}u_{k+1} - \frac{1-e^{\beta^-\Delta}(1-\beta^-\Delta)}{\beta^-\Delta}u_k. \quad \text{(C.1.18)}$$

C.2 Investment Thresholds and Option Values

C.2.1 Production Tax Credits

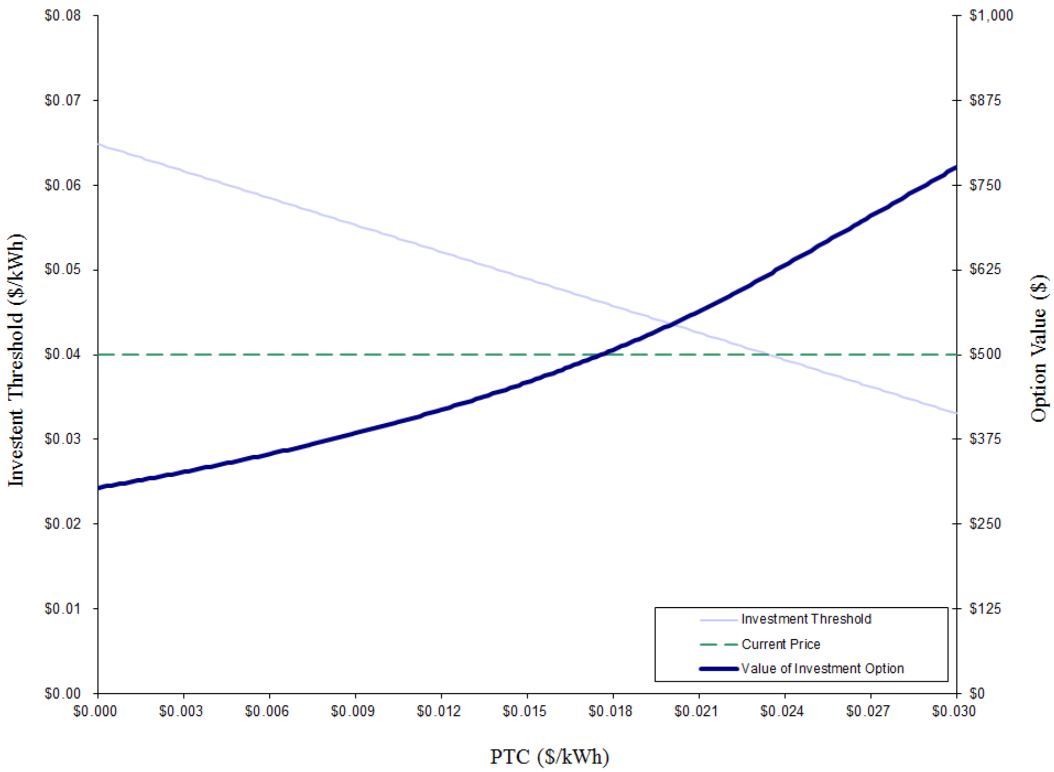

Figure C.1: Investment Threshold and Option Value by PTC: Basic Model

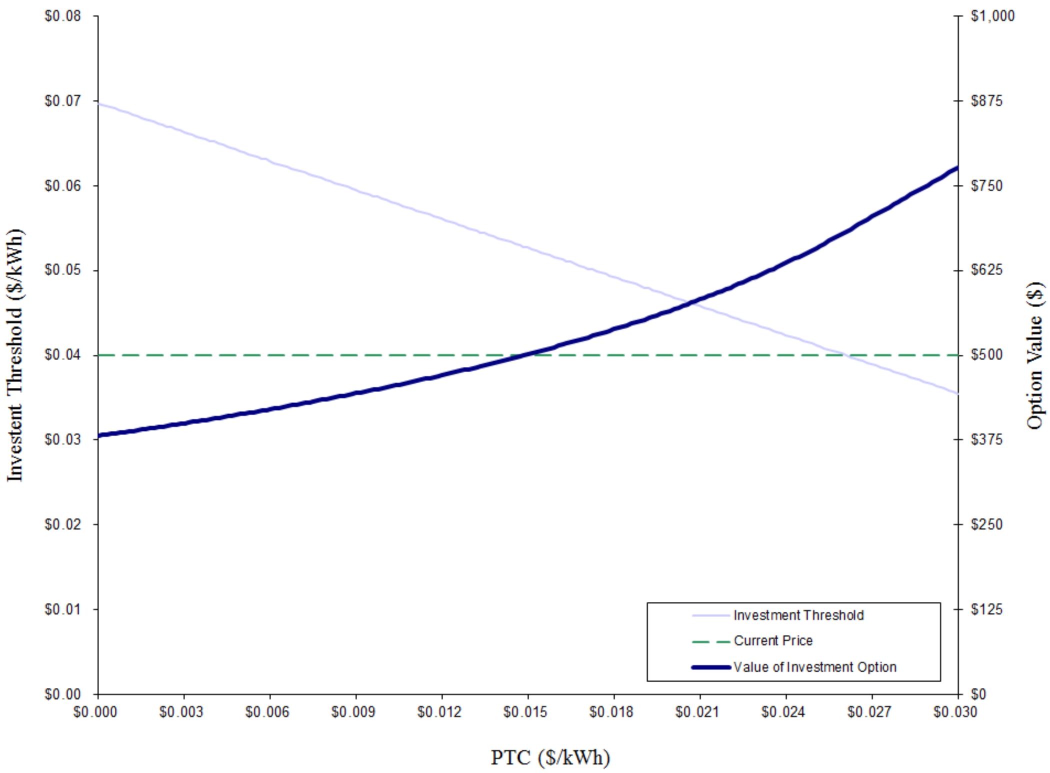

Figure C.2: Investment Threshold and Option Value by PTC: Deregulation

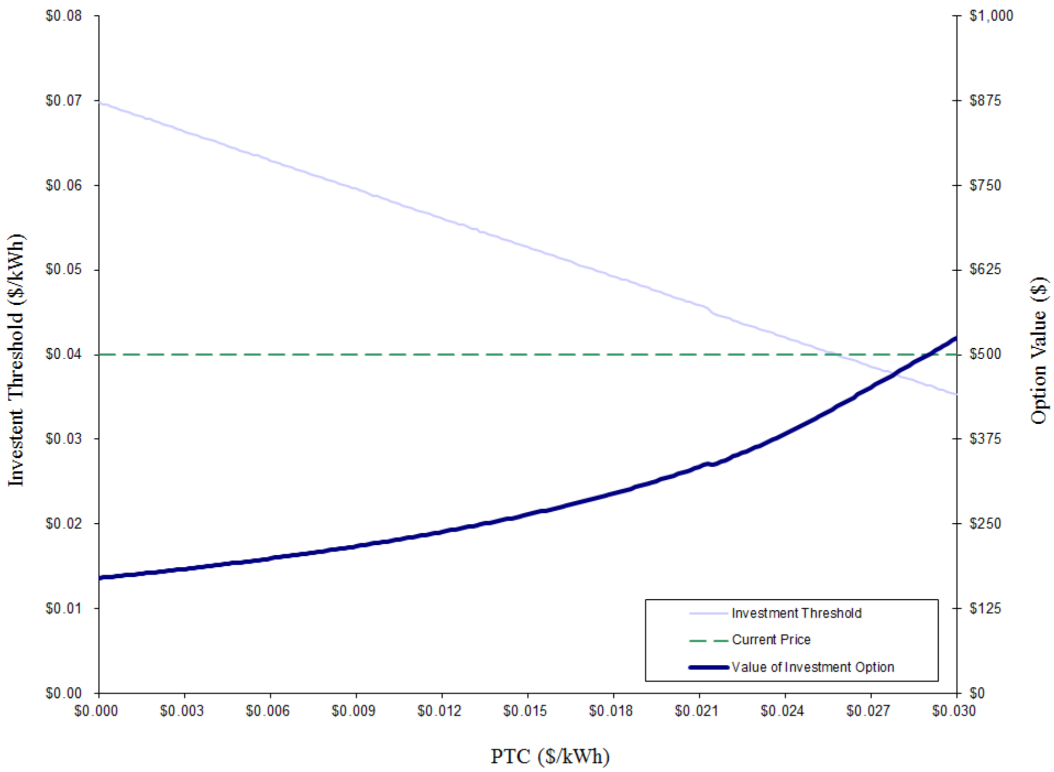

Figure C.3: Investment Threshold and Option Value by PTC: Booms and Busts in Oil Prices State 1

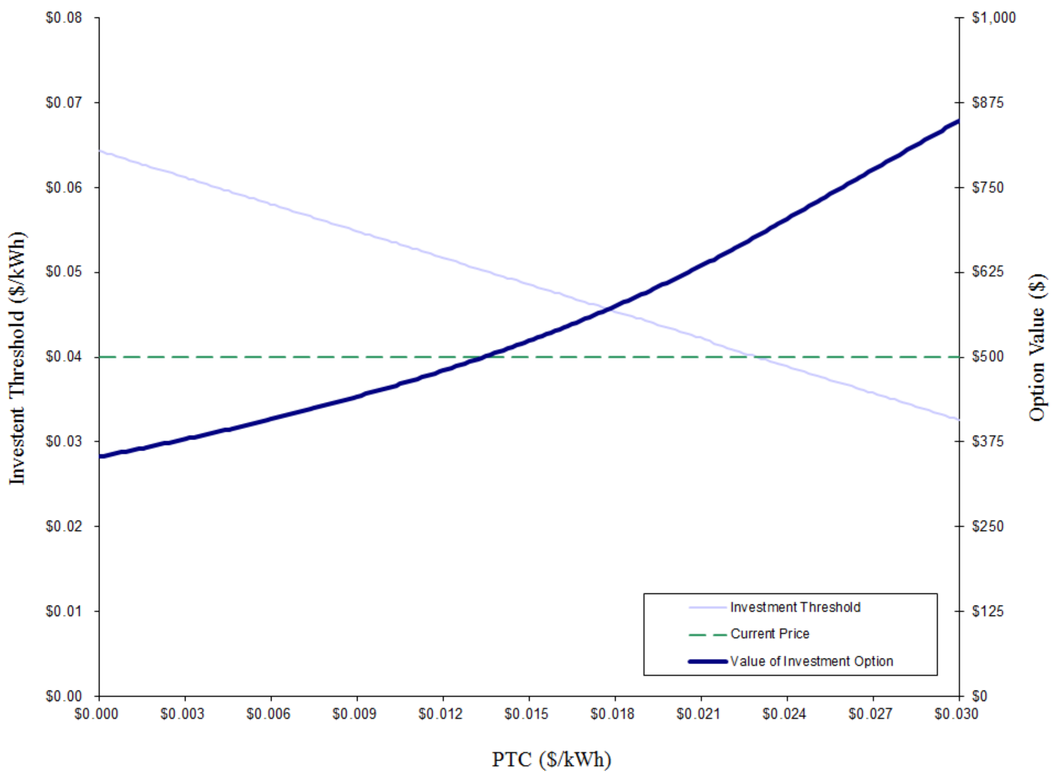

Figure C.4: Investment Threshold and Option Value by PTC: Booms and Busts in Oil Prices State 2

C.2.2 Capital Costs

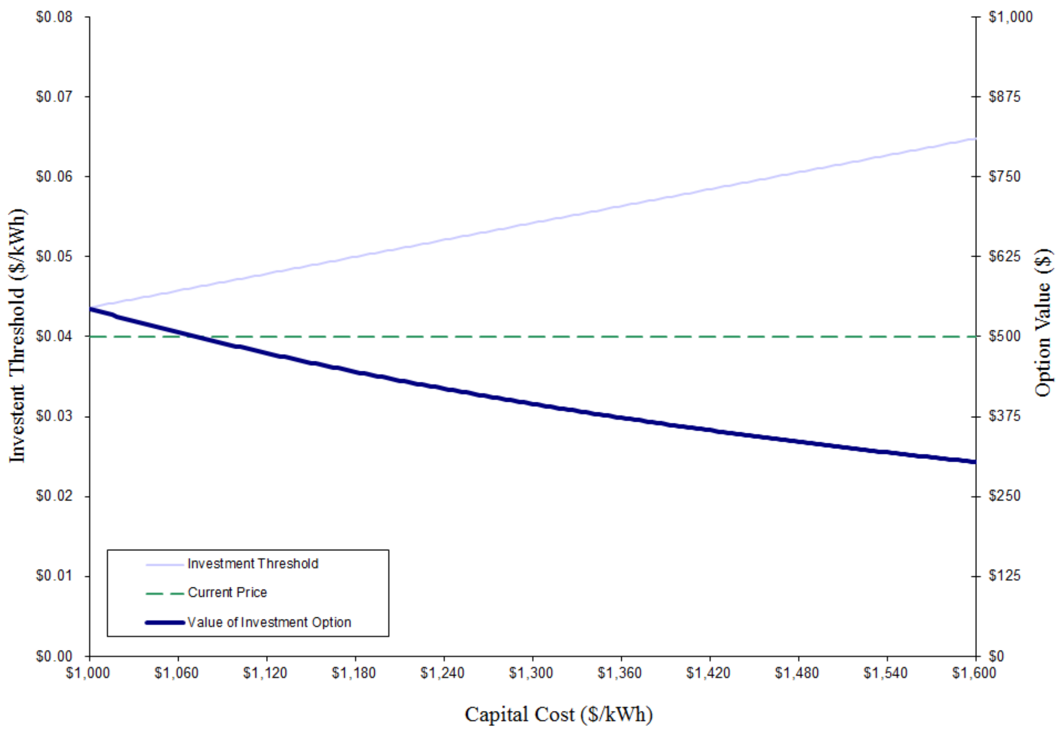

Figure C.5: Investment Threshold and Option Value by Capital Cost: Basic Model

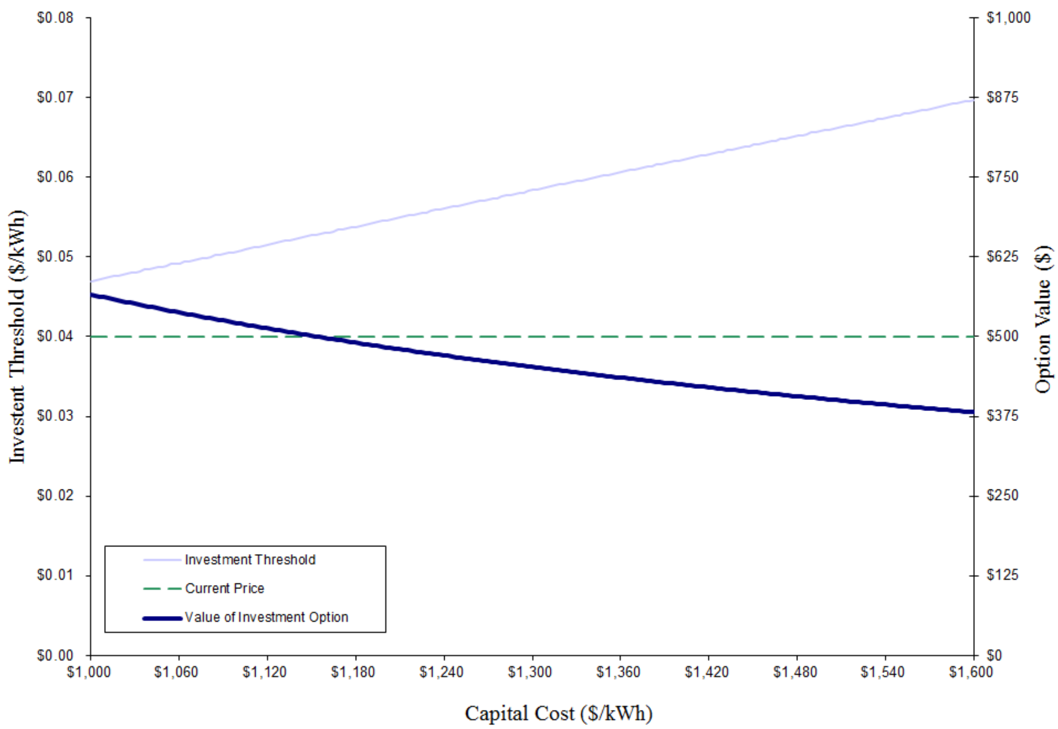

Figure C.6: Investment Threshold and Option Value by Capital Cost: Deregulation

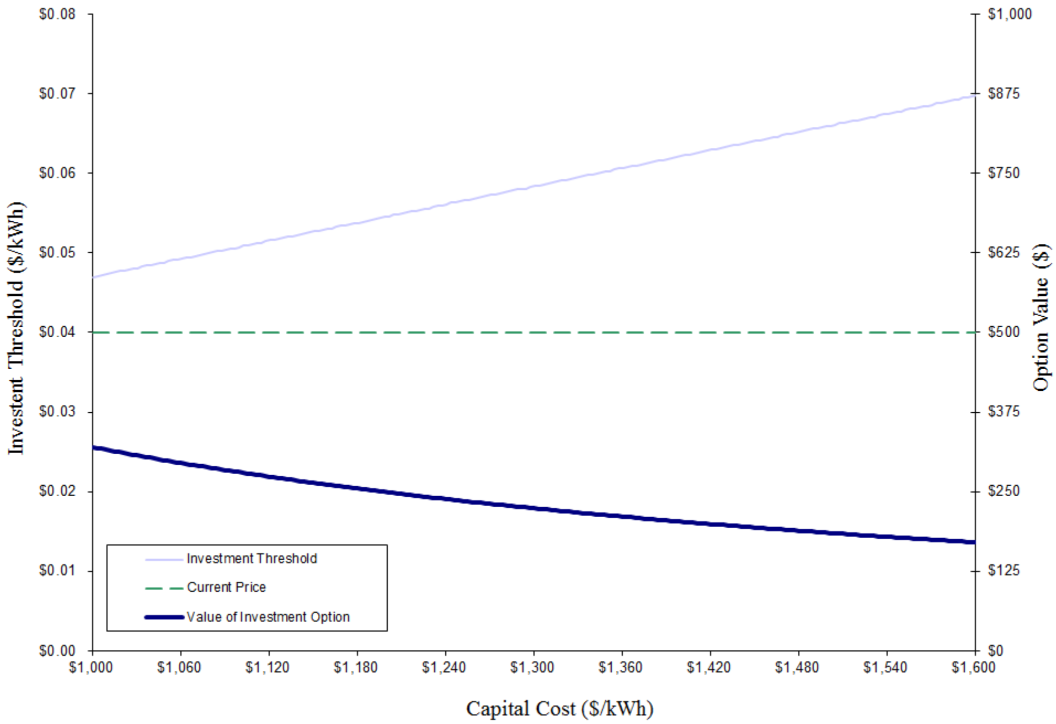

Figure C.7: Investment Threshold and Option Value by Capital Cost: Booms and Busts in Oil Prices State 1

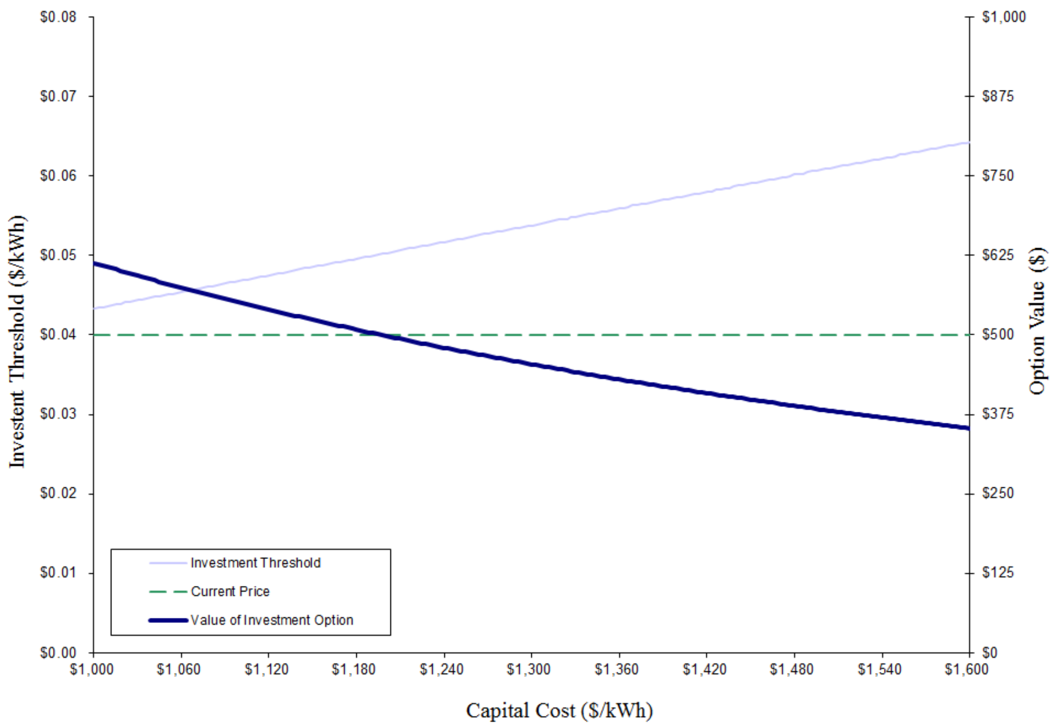

Figure C.8: Investment Threshold and Option Value by Capital Cost: Booms and Busts in Oil Prices State 2

C.2.3 Utilization Rate

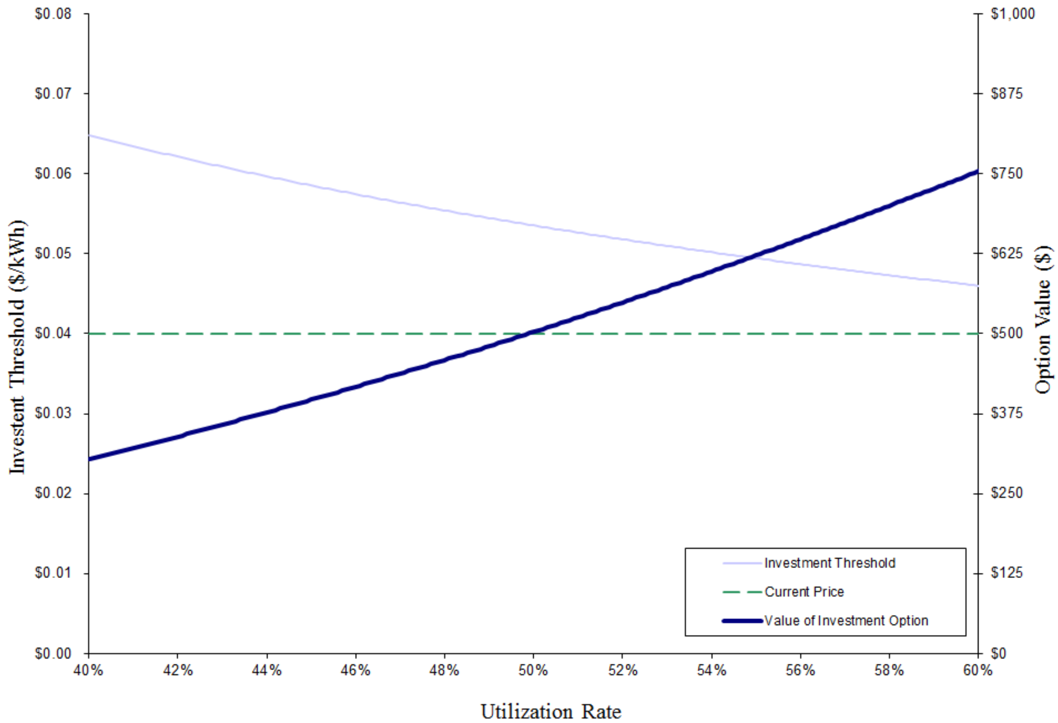

Figure C.9: Investment Threshold and Option Value by Utilization Rate: Basic Model

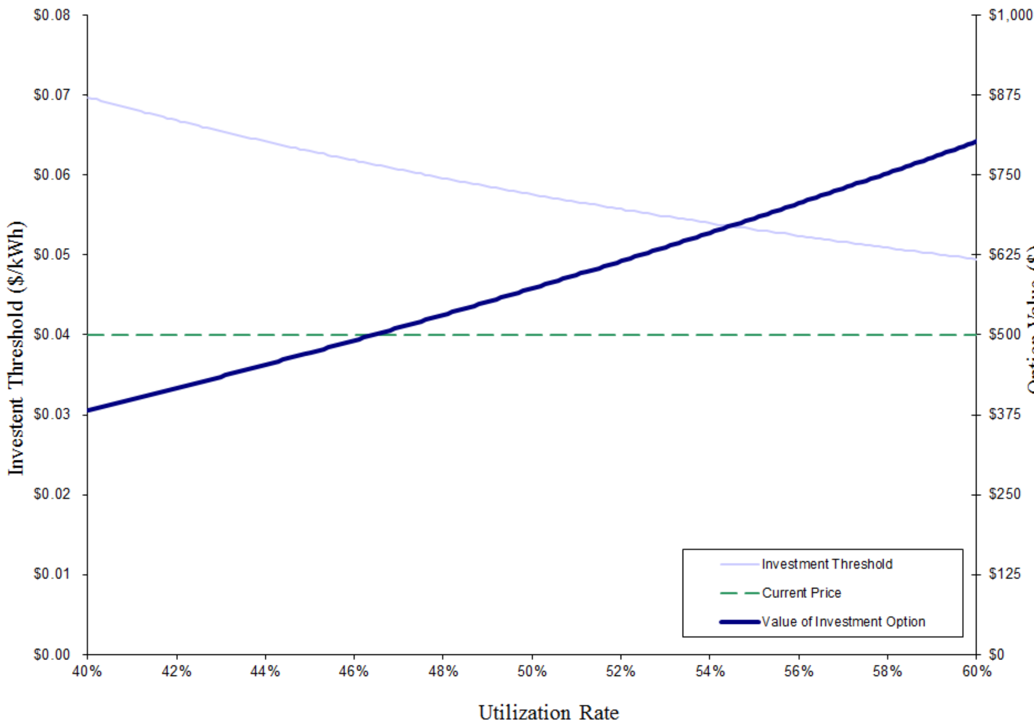

Figure C.10: Investment Threshold and Option Value by Utilization Rate: Deregulation

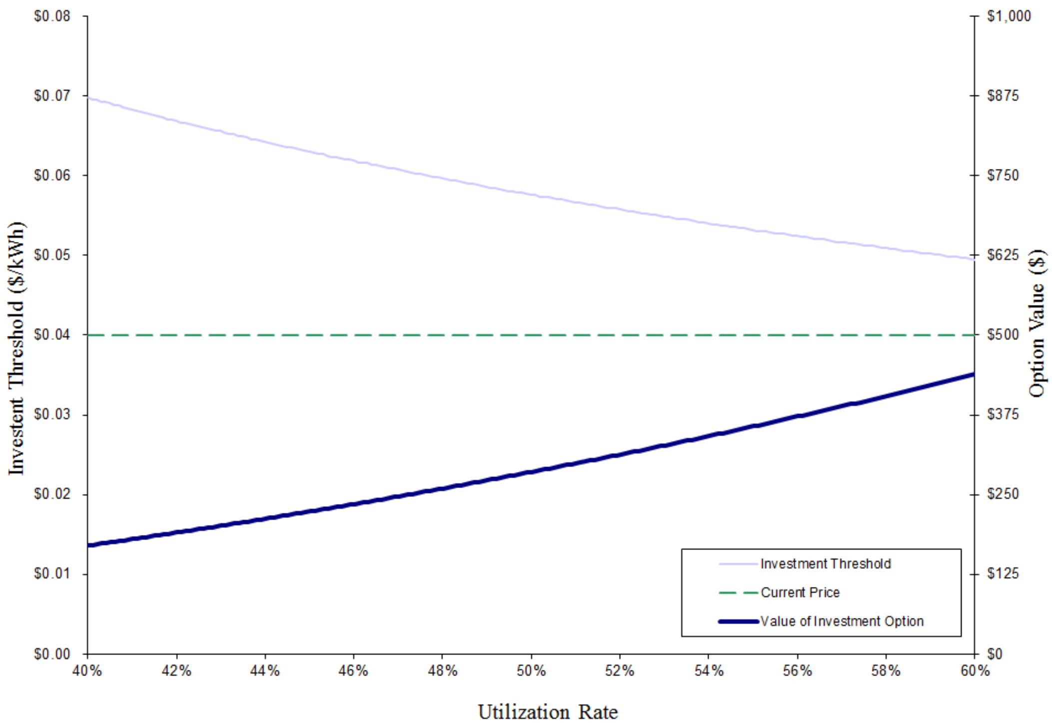

Figure C.11: Investment Threshold and Option Value by Utilization Rate: Booms and Busts in Oil Prices State 1

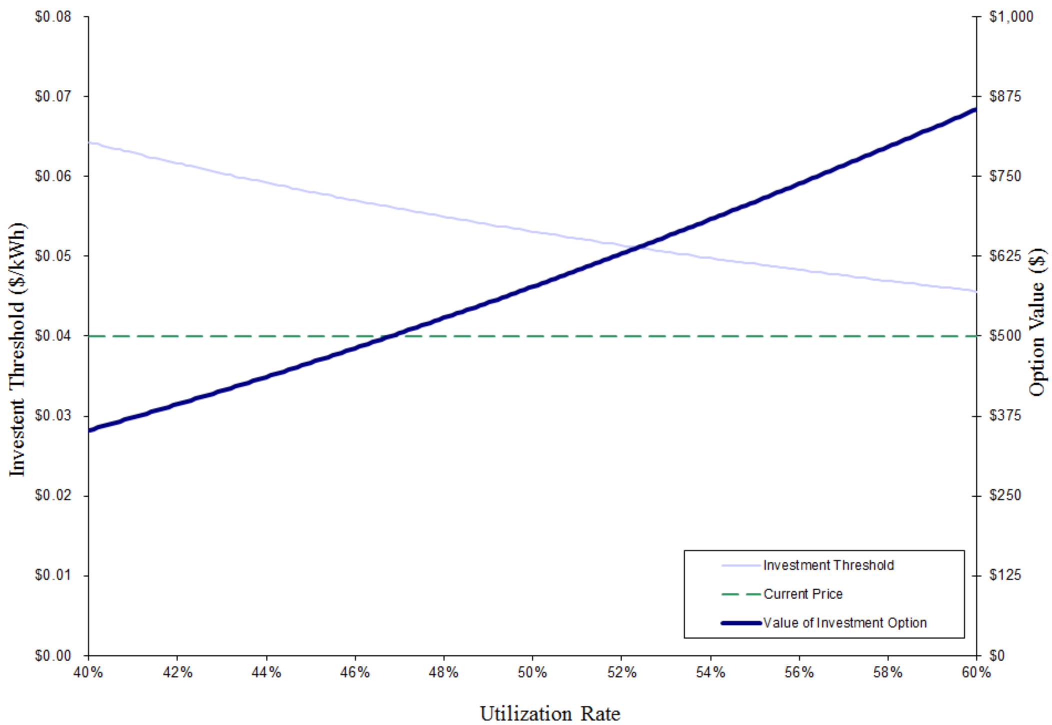

Figure C.12: Investment Threshold and Option Value by Utilization Rate: Booms and Busts in Oil Prices State 2

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